REPORT

THE SCREWWORM PROBLEM

IN THE SOUTHWESTERN UNITED STATES AND NORTHEASTERN MEXICO

With

Comments on Control and Eradication

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SUMMARY

The screwworm has been a pest of warm-blooded animals in the southwestern states for over 100 years. Infestations also occur in Mexico, Central America, and South America. A majority of livestock owners in the Southwestern United States consider the screwworm to be a serious pest of domestic animals, particularly in Texas, California, and Arizona, and to a lesser extent in New Mexico and Louisiana. Many of the stockmen in Mexico did not consider the screwworm to be a serious pest. The average annual loss due to screwworm attack in the Southwestern United States is estimated at $20 to $25 million. No estimate has been made of the losses in Mexico.

The 1959 survey revealed that screwworms ordinarily survive and remain active during the winter months in Texas, California and Arizona, and throughout northeastern Mexico. The overwintering area in the United States approximates 150,000 square miles, about one-half of which is in Texas.

Under average conditions screwworm infestations can be controlled and losses due to screwworm attack can be prevented if good livestock practices are followed and adequate facilities are available for the proper handling of livestock. Effective remedies are available for the treatment of screwworm infestations and for the prevention of reinfestation. The numerous reports that screwworms are of minor importance in Mexico are probably due to the fact that many herds are under the constant care of a herdsman where screwworm infestations are promptly treated. Control could probably result from the continuous, systematic release of sterilized male flies. The degree of such control would be in proportion to the extent of the area treated and the number of flies released.

The theory of eradicating screwworms by overwhelming the native population with sterile male flies is fundamentally sound. However, because of the large area involved and the constant source of reinfestation from Mexico, such a program in the Southwestern United States is not feasible without a similar program in Mexico.

With reference to a United States-Mexico cooperative screwworm eradication program, it is believed that such an undertaking should begin with the development of more basic information and improved operational techniques. A number of plans for screwworm programs whereby screwworm eradication might be attempted, are presented with extent of areas involved in each plan and estimated costs.

THE SCREWWORM PROBLEM
IN THE SOUTHWESTERN UNITED STATES AND NORTHEASTERN MEXICO
With
COMMENTS ON CONTROL AND ERADICATION

The Screwworm

The screwworm is the larva or maggot of the screwworm fly, Callitroga hominivorax,(Coqrl.) and is a true or obligatory parasite. The larva is called a screwworm because the rings of spines encircling its body and its tapered shape somewhat resemble a wood screw. In nature it lives only on the live flesh of warm-blooded animals, and infestations have been found in practically all species of wild and domestic animals, poultry and man. Screwworms are not found in cold-blooded animals, such as: turtles, snakes, lizards; nor are they found in carcasses, decaying meats, necrotic tissues, and decayed vegetable matter. Maggots found in these animals and materials are the larvae of common blow flies.

The screwworm fly will lay its eggs on an animal only when there is a break in the body surface. All types of cuts, abrasions, punctures, or diseased skin are subject to infestation. Common predisposing causes of screwworm attack include: navels of newborn animals, snags and scratches, surgical operations, shear cuts, brands, dog bites, wounds from fighting, fly and tick bites, ear-marking, punctures in the udders of sows made by the needle-like teeth of sucking pigs, "sore mouth" in sheep and goats, and gunshot wounds. Any open wound is attractive to the female screwworm fly. Infested wounds become increasingly attractive to the female fly; consequently, such wounds are continuously reinfested.

The eggs are deposited in shingled batches in or along the edges of wounds, and as many as 400 may be deposited at one time. The eggs hatch

in less than one day. The larvae eat into live tissues and soon form a "pocket" in the flesh. After completing development, which takes about five to six days, the larvae drop from the wound and burrow into the soil where the outer skins harden and form pupae. Seven to ten days later the flies emerge and in about six days they are ready to lay eggs. During cool weather the pupal stage may persist for two months. The average life cycle of the screwworm is approximately 24 days.

History of the Screwworm in the United States

Screwworms occur generally in Mexico, Central America, South America, and in many of the islands in the West Indies. They have been a problem in the southern portions of Texas, New Mexico, Arizona and California for many years, and infestations were reported in Texas as early as 1825.

Screwworms were unknown in the Southeastern States until the summer of 1933 when infested animals were brought into southern Georgia with the movement of cattle from the drought stricken Southwest. Within two years screwworms spread throughout the Southeast and became established in peninsular Florida, where mild winters permit year around activity of this semi-tropical insect.

Each spring, with the onset of warm weather, the flies migrate northward at an average rate of 35 miles per week. From the overwintering area in peninsular Florida they usually spread into Georgia, Alabama, Mississippi, South Carolina and, less frequently, into North Carolina, Tennessee and Virginia. From the southern extremities of California, Arizona, New Mexico and Texas, they spread throughout the major portions of those States and into Louisiana, Arkansas, Oklahoma, and Kansas. The transportation of

infested livestock frequently initiates localized infestations in states as far north as the Dakotas and New Jersey. Cold weather each winter kills out the screwworms in all but the semi-tropical overwintering areas.

It is impossible to accurately estimate the losses due to screwworm myiasis. Losses are not confined to the deaths of animals, but include cost of labor to ride herd and treat infestations, cost of pesticides, reduced value of stunted calves and animals that have lost an eye or ear, susceptibility of infested animals to other diseases, etc. Losses fluctuate from year to year due, primarily, to variation in weather conditions. Following a warm winter, when conditions are favorable for screwworm activity, losses are usually heavier and extend over a much greater area than those following a cold winter. The average annual losses in the Southeast have been estimated at $20 million. It is believed that the average annual losses in the Southwestern United States will approximate $20 - $25 million. These estimates do not include losses to wildlife. Losses in Mexico have not been estimated.

The Screwworm Survey in the Southwestern United States

A preliminary fact-finding screwworm survey was made during January-April 1959 in California, Arizona, New Mexico, Texas and Louisiana, to determine the incidence, seasonal abundance, and overwintering areas, and to obtain other pertinent information relative to the screwworm problem. The survey was conducted by Animal Disease Eradication Division personnel with the collaboration of the Agricultural Extension Services, State Departments of Agriculture, practicing veterinarians and livestock owners. To obtain adequate information a minimum of ten persons, including the County Agricultural Agent, local veterinarian, and stockmen, were interviewed in

each county. The information was consolidated on a county report form and transposed to a state report. In compiling this final report, an attempt was made to coordinate the screwworm data with the topography and climate of the region, and with the distribution of screwworm hosts, i.e., wild and domestic animals susceptible to screwworm attack. Such a preliminary survey is by no means exhaustive, but it serves to provide a general picture of the screwworm problem, delineates areas where more intensive surveys may be desired, and provides a general idea of the scope and complexity of a control or eradication program.

A series of maps (see index) showing average annual screwworm infestations, overwintering areas, January temperatures, screwworm hosts, distribution of wild and domestic animals, and high altitudes in the overwintering areas, are included to more clearly present the pertinent information relative to the screwworm problem in the Southwestern United States and Mexico. The data for the maps showing the distribution and value of domestic animals was obtained from the several states. More recently the U.S.D.A. Agricultural Statistics - 1958 appeared in print so the revised numbers and values of each species of domestic animals, for each state, are shown on pages 31 and 32.

The delineation of areas where screwworms survive and remain active during the winter months is of importance to a control or eradication program for it is in these areas where most of the control or eradication activities must be effectuated. These activities are to suppress screwworm populations in the overwintering areas and to prevent the northward migration of flies into uninfested areas.

The average overwintering areas in the Southwestern United States include portions of Arizona, California, New Mexico and Texas (Fig. 2). They are within and south of the isocheim of about 55°F. Other meteorological factors, such as: precipitation, humidity, evaporation, sunshine, etc., together with geographical features of the areas also contribute to the environment that influences the survival of screwworms. Climate determines the presence or absence of screwworms; population densities of susceptible hosts determine the relative abundance of the insect. Warm moist climates and heavy concentrations of warm-blooded animals are favorable for the propagation of screwworms. Periodic fluctuations in winter climatic conditions are responsible for variations in the extent of the overwintering areas; consequently, such areas are larger during mild winters and smaller in severe winters.

Screwworm infestations are generally light and scattered in all of the overwintering areas. Medium to heavy populations are seldom reported during the winter months, and then only in localized areas during exceptionally mild winters.

The total area where screwworms overwinter in the Southwestern United States approximates 150,000 square miles (Fig. 2). This includes 46,000 square miles in California, 34,000 in Arizona, and 70,000 in Texas. Screwworms seldom overwinter in New Mexico and Louisiana.

In California the overwintering area extends from the Mexican border into the Imperial Valley, through the San Bernardino Mountain passes and into the San Joaquin Valley (Fig. 17). It includes all or parts of Imperial, San Diego, Riverside, San Bernardino, Los Angeles, Kern, Kings, Tulare and Fresno Counties. This peculiar configuration of the

overwintering area is due to the unusual topography of the State and its related climatic condition (Fig. 17). In most other regions of the United States, latitude is the major determinant of temperature, but in California the isotherms have mostly a north-south instead of an east-west trend, following topographic contours rather than parallels of latitude (Fig. 4). Hence the winters are mild throughout the Great Interior Valley (Sacramento and San Joaquin Valleys), latitude considered, as is evidenced by the growing of citrus fruit and other subtropical plants as far north as Tehama County.

The overwintering area extends eastward from southern California across southern Arizona in a 100-mile band adjacent to the Mexican border (Fig. 7). This area includes all or parts of Yuma, Maricopa, Pinal, Pima, Santa Cruz, Cochise and Graham Counties.

Screwworms do not, ordinarily, survive the winter in New Mexico, but they occasionally overwinter in the southwestern counties of Hidalgo, Grant, and Luna, an area of approximately 10,000 square miles (Fig. 2).

Texas has the largest screwworm overwintering area, some 70,000 square miles, and serves as a breeding ground for fly populations that migrate northward each spring and infest the other south-central states. The northern limit of this overwintering area extends from Jeff Davis County eastward to Galveston County and circumscribes 55 southern counties (Fig.43).

The Screwworm Survey in Northeastern Mexico

Screwworms survive throughout the year in southern portions of several of the southwestern United States bordering on Mexico. The screwworm survey recently completed in California, Arizona, New Mexico, Texas, and Louisiana established overwintering areas and provided additional pertinent information on the screwworm problem in those states. It is a matter of record, with the Mexican Department of Agriculture, that screwworms are prevalent in Mexico.

In order to accumulate more definite information on the screwworm problem in Mexico, and to better determine the feasibility of a control or eradication program by use of the sterile-fly technique, Department of Agriculture officials from both countries met in Monterrey, Mexico, during February 1959 and made arrangements for a joint survey of the northeastern portion of Mexico. It was agreed that the survey activities would begin in the Gulf Coast region near Matamoros, Tamaulipas, and progress southward and westward. The purpose of the survey was to determine the incidence and relative abundance of screwworms; the effects of climate, terrain, livestock practices, and other factors on the screwworm population in the different areas; and the existence, if any, of a natural barrier through which screwworms cannot migrate.

Because of a general similarity between cattle populations, climate, and terrain in the coastal regions of Texas and the adjacent areas in Mexico, it was believed certain that screwworm would be found in medium to heavy populations along the entire Gulf Coast of Mexico. There was some hope, however, that the plateau region, covering much of the interior portion of the country, would be found either free of screwworms or with

very light populations during some short periods of the year. It was believed also that the cooler weather and occasional frost in the mountainous region extending across the center of the country, and in the Sierra Madre chain of mountains running in a southeasterly direction from Nogales, might cause these areas to be screwworm-free throughout the year.

Vehicles were made available during April and operations with four survey teams were in progress in the State of Tamaulipas by the end of the month. Through the assistance of Dr. Jose Casaneda, Mexican Department of Agriculture veterinarian, who was assigned to the survey unit, excellent cooperation was obtained from other Mexican Department of Agriculture veterinarians stationed throughout the country, and from cattlemen's associations, local officials, packing and slaughterhouse personnel and many other representatives of the livestock industry in Mexico. The survey covered all or parts of the following states: Tamaulipas, Veracruz, Puebla, Tlaxcala, Hidalgo, Queretaro, Guanajuato, San Luis Potosi, Nuevo Leon, Zacatecas, Durango, Coahuila, Chihuahua, Jalisco, Michoacan, Mexico and Aguascalientes.

Evidence of year-round screwworm activity was found to be rather general in each of the states surveyed with the exception of Tlaxcala. In this small state there was no evidence of screwworm activity at any time during the year. Several livestock owners in different states reported screwworm activity at altitudes as high as 8,000 feet and a few reported screwworm activity throughout the year at this altitude. The soil over much of Mexico is of volcanic origin and quite dark in color. There are few cloudy days at high altitudes during the winter months

and the sun's rays provide greater warmth to the soil than in regions further removed from the Equator. The dark soil absorbing and holding more warmth than at points further north may explain why pupae are able to survive in the soils at high altitudes despite the relatively cool weather.

A surprising number of livestock industry representatives indicated screwworms to be of minor importance to them. This might be accounted for by the fact that so many herds of livestock in Mexico are attended daily by a herdsman instead of being permitted to graze in pastures or on open range unattended. In the absence of an abundant wildlife population, this practice alone would serve to keep screwworms from building up into a heavy population within such areas.

Because of variable storm conditions, the coastal portion of Mexico may receive rainfall during any month of the year. In central Mexico, however, the rainy season usually lasts from May through October. Many ranchers reported increased screwworm activity following rainy spells. In the area surveyed, screwworm activity seemed to be greatest from March through October with peak activity during May and June and another peak during September and October.

It must be concluded from the survey that there is little likelihood of a natural barrier existing in Mexico that will prevent the migration of screwworm flies.

In the absence of natural barriers, it appears that any proposal for applying the sterile fly technique in Mexico must be associated with control procedures, or with the use of barrier zones.

Screwworm Control

Screwworm infestations in domestic livestock can be controlled. Losses due to screwworm attack can be prevented if good livestock management practices are followed and if adequate facilities are available for the proper handling of livestock. This means the frequent inspection and prompt treatment of infested wounds during the season of screwworm activity. The majority of infestations are in the navels of new-born animals and in man-made wounds such as castrations, ear-marking, brands, dehorning, and shear cuts. Therefore, the close inspection of new-born animals, and the proper treatment of man-made wounds are imperative for effective screwworm control. It is recognized that carrying out these practices on large ranches may cause inconveniences, difficulty and considerable expense, but the screwworm season is comparatively short in most areas and effective remedies are available.

Smear 335, a screwworm remedy developed by Entomology Research personnel, is effective in killing screwworms in a wound and in protecting the wound from reinfestation for several days. Other effective remedies, including EQ 62, are also available in most screwworm infested areas.

More recently sprays have become available which, when applied to livestock, will kill the screwworms in an infested animal, and protect the animal from reinfestation for a period of from 3 to 4 weeks. These sprays also control other ectoparasites, such as: lice, ticks, and horn flies.

The effectiveness of a determined effort to control screwworms was demonstrated in Florida during 1935-38, when the U. S. Bureau of Entomology and Plant Quarantine, in cooperation with the Southeastern States, conducted a Screwworm Educational and Control Program. Within about 1½

years the number of screwworm infestations decreased from about 20,000 per month to less than 50 per month with no losses of livestock. Such control was possible in spite of the fact that crude remedies (benzol and pine tar oil) were used at that time. It would be expected, therefore, that under average conditions, similar results can be obtained elsewhere.

Control of screwworms by the release of sterile male flies would be effective in proportion to the extent of the area covered and the number of flies released per square mile per week. Such a control program would be effective for only such period of time as it is in operation, and the treated area would be immediately reinfested from adjacent areas at the cessation of such activities.

Screwworm Eradication

The excellent results being obtained in the Screwworm Eradication Program in the southeastern states has generated considerable interest among livestock owners as to the possibility of eradicating screwworms from the Southwest.

In evaluating an eradication program of such magnitude, consideration must be given to several factors that may contribute to the success or failure of such a program. Eradication means a complete elimination of the pest from a predetermined area and the protection of that area from reinfestation; whereas control is characterized by a significant reduction in fly populations with a continuous holding program to prevent the build-up of fly populations to numbers of economic importance.

The method of eradication now being used in the Southeast is to prevent native flies from reproducing. Female screwworm flies mate only once.

Male flies, reared in a laboratory and sterilized by irradiation with gamma rays, are released to mate with native females in competition with native males. Females that mate with sterilized males lay eggs that do not hatch. If enough sterilized males are systematically released to overwhelm the native flies, the population quickly declines. If the release of sterilized male flies continues long enough, and the treated area is protected from reinfestation, eradication of the species will result. Details of the research leading up to the development of the sterilizing technique, and other methods of control, are explained on pages 22 - 30.

A Screwworm Eradication Program in the southwestern states would not be successful without a similar program in Mexico where, presumably, the screwworm is active throughout the year, and is a constant source of reinfestation to our bordering states. A program in Mexico must extend southward from our border to some natural barrier that would prohibit the northward movement of screwworm flies, or to a point where a buffer zone could be established. This buffer zone or artificial barrier, would be a strip of land of undetermined width, from the Gulf of Mexico to the Pacific Ocean, where sterile male flies would be systematically and continuously released to prevent the infiltration of fertile flies into the eradication area. The program in Mexico must also include an effective quarantine to prevent the movement of infested livestock from the infested areas, and from ports of entry, into the screwworm-free areas - including the southwestern United States.

The Screwworm Eradication Program in the Southeast has had many advantages that contributed to its success, advantages that cannot be expected to aid a program in the Southwest. The screwworm, being a subtropical

insect is usually killed out each winter in all but the southern extremities of the southwestern states and in peninsular Florida in the Southeast. The infested area in the Southeast was confined chiefly to peninsular Florida, an area of approximately 50,000 square miles, protected from reinfestation by a water barrier on the east, south and west, and by the cold winter on the north. The problem in the Southeast, therefore, was to eradicate screwworms from the overwintering area where there was little or no hazard of reinfestation from circumjacent areas.

In addition, the need for solutions to several unanticipated problems arose in the Southeast, and these should be solved before embarking on an eradication program in the Southwest. The limitations of the sterilized fly techniques in eradicating screwworms were not established by the program in the Southeast. There the release of sterile flies was started early in 1958 following the most severe winter recorded since screwworms first invaded that area in 1933. Cold weather killed most of the screwworms in north Florida, excessive rainfall drowned most of them in the southern part, and only light populations survived in the rest of the State. Prompt initiation of a limited eradication program prevented the build-up of fly populations until full-scale operations started in July. During the whole year there were less than 1,000 screwworm infestations in Florida, whereas in normal years there were an estimated 20,000 cases per month.

Even with low fly populations throughout the State of Florida, some difficulty was experienced in eliminating a localized infestation in Broward, Dade and Palm Beach Counties. Theoretically the release of 500 sterile male flies per square mile per week would eventually eliminate

screwworms from an area with an average infestation. In this case, however, the infestation persisted for weeks even with the release of over 9,000 sterile males per square mile per week. Ultimate eradication finally resulted from the release of this tremendous number of sterile males, the spraying of cattle with Co-Ral, riding herd on horseback to treat the navels of new-born calves and the extensive use of fly traps. It has not been definitely determined just what factors were responsible for the persistence of this infestation. It does suggest, however, the need for a careful review of eradication operations and the development of improved techniques.

Greater efficiency and economy can be attained with more knowledge of the following: (1) nutritional requirements of screwworm larvae so as to develop an improved and more economical larval rearing medium; (2) precise data on irradiation dosage, rate of dose, optimum age of pupae when irradiated, so as to produce sterile male flies without seriously impairing their sexual vigor and longevity; (3) attractants for screwworm flies, so as to induce oviposition of native females and to lure them to traps, as aids to field surveys; (4) development of a strain of artifically reared flies with maximum vigor, mating habits, and longevity; (5) the practicability of flying larger planes at higher altitudes to obtain a wider swathe-width and carry a greater load of flies; and the development of improved operational methods.

The theory of eradicating screwworms by overwhelming the native population with sterile male flies is fundamentally sound. Basic techniques in the rearing and sterilization of flies have been developed by the Entomology Research Division. The soundness of the theory and the

workability of the techniques have been adequately demonstrated by the successful eradication of screwworms from the 170 square mile island of Curacao. The procedures used in Curacao were tested in small areas in Florida with satisfactory results, and then, with some improvements, were used in the present successful eradication program in the Southeast.

While the techniques used in the production, sterilization and dispersal of sterilized male flies were effective in eradicating screwworms from lightly infested isolated areas, the refinement of the techniques is essential to an eradication effort in the Southwest. Methods and materials should be developed to improve techniques in rearing, sterilization, dispersal, and related activities so the dispersed flies compare favorably with native flies as to vigor, mating activity and longevity, at the most economical cost.

Regulatory personnel recognize the need for basic research and the necessity for the development and improvement of operational techniques to properly effectuate a control or eradication program in the Southwest. The solution to the problems enumerated above will enhance the probability of success in a program of such magnitude and complexity.

Research and Development

Pioneering research on the sterile-male method of screwworm eradication led to the development of satisfactory procedures for the elimination of this pest from the Southeast. The same procedures will not necessarily be applicable under conditions and circumstances existing in the Southwest. The screwworm area in the Southwest is much larger than in the Southeast and differs in terrain, vegetation, and climate. In addition, there is a vast contiguous area in Mexico that will serve as a continuing

source for reinfestation unless that area is also made free of screwworms or an effective barrier can be established by the continuous release of sterile flies.

The situation in the Southwest, therefore, demands answers to several major problems before the requirements for a successful screwworm control or eradication program can be estimated and the program carried forward with reasonable confidence of success.

It should be pointed out that an eradication program based on the methods and procedures applied in the Southeast could be too costly and/or ineffective in dealing with the problems in the Southwest.

It is essential, therefore, that research be conducted to test current procedures and develop effective and economical methods that are applicable to conditions prevailing in the Southwest. The entomologists and other scientists conducting research on the problem in the Southeast were well aware of the desirability of improvements in certain phases of the operations in that region for the most efficient eradication program. However, a recommendation to further delay the eradication effort for several years until the desired information could be developed would in the meantime have subjected the livestock interests and other values to continued losses by the pest which would have greatly exceeded the savings that could have been expected in the conduct of an eradication program at a later time.

Basic Research Needs to Support an Eradication Program in the Southwest

Because of the scope of the entire project it will be essential to develop procedures that are of maximum effectiveness and economy in the eradication of the insect from infested areas and to prevent re-establish-

ment of the insect from joining areas still infested. The major lines of research needing attention are discussed below:

1. Nutritional Studies

Maximum efficiency and economy in the culture of sterile flies required for an eradication or control program of the scope required for the Southwest is of vital importance. The number of flies needed to eliminate the natural fly population cannot be estimated accurately at this time, but it can be expected to be large because of the large area involved and the high population of natural flies in certain parts of the area. Moreover, it is likely that successful control will eventually revolve itself into a program of continuous release of sterile flies to serve as a barrier zone to prevent re-establishement of the insect.

Basic research on the nutritional requirements of the screwworm for the purpose of developing the most economical procedure for rearing vigorous and long lived insects is necessary. Such research should start with the development of chemically defined diets to establish the essential elements required for such diet. It is known that flies reared by current procedures do not live as long nor are they as vigorous as are natural flies reared from animal wounds. The development of improved nutritional media for the culture of screwworm flies that are fully competitive or superior to natural flies could more than double the efficacy of flies now produced for screwworm eradication.

2. Effects of Irradiation on Screwworm Flies

Exposure of screwworm pupae to gamma rays reduces the sexual vigor and length of life of the insect to some extent. The flare-up of screwworms in Broward County, Florida, in spite of the release of considerable

numbers of sterile flies might have been due to reduced vigor because of irradiation damage.

An intensive basic research program with adequate irradiation facilities should be undertaken to determine (1) the optimum dosage of radiation at different temperatures, (2) optimum radiation rate, (3) optimum age for pupae irradiation, and (4) optimum conditions for handling the pupae and flies after irradiation. As with nutritional studies, the vigor and length of life of the sterile flies might be increased substantially, thus contributing to greater efficiency and economy in a control or eradication program.

3. Attractants

A good attractant for the screwworm is needed to: (1) permit accurate estimates of the fly population throughout the control area so that adequate numbers of sterile flies can be released in areas of high population density and to limit the number to the minimum where fly densities are low (2) measure the progress of control or eradication effort (3) detect low level screwworm infestations as quickly as possible so that control or eradication efforts can be initiated before the insects build-up to damaging numbers or to terminate releases as soon as possible after eradication has been achieved. Research on attractants in the past had indicated some important leads but a successful attractant has not been developed.

The importance of good reliable means of detecting insect populations, when the infestations are at a low point, cannot be overestimated. If a survey method was sufficiently sensitive to determine the absence of screwworms with complete confidence, sterile fly releases in all probability could be terminated months sooner in much of the Southeast with

substantial saving in cost of the program. Potential saving in the Southwest over a period of years could amount to millions of dollars if a satisfactory method of screwworm fly detection could be developed.

Research on attractants should have as its objective the development of methods and materials which attract flies for oviposition as well as to lure flies to traps.

4. Genetic Studies

Several problems involving genetics need investigation with a view to the development of a control or eradication program with maximum effectiveness. In efforts to determine the presence of natural populations of screwworm flies, it would be of great value to be able to distinguish the released sterile flies from the native wild flies. This could be done by developing a strain of screwworms which carry a distinguishing mark. Various strains of screwworm flies from different parts of the infested regions in the Southwest and Mexico need to be investigated to determine if they are equally adapted to all areas. It is possible that screwworms from the West Coast, for example, are physiologically better adapted for survival in that climate than are screwworms on the more humid East Coast. Selection of fly strains for release in various areas which are most likely to survive and compete successfully with the native flies would be an important phase of the research.

5. Special Pilot Eradication Experiments

Prior to the initiation of an eradication program, it is regarded essential to undertake large scale pilot eradication tests. The purpose would be to determine the number of flies needed to eradicate the insect in the Southwest and to determine the width of barrier zones and the number of sterile flies needed to prevent re-establishment of the insect.

Research of the nature outlined above should be initiated as soon as possible and maintained during the eradication effort. Professional personnel, well trained in various scientific disciplines, will be required for the research. They should be provided with adequate technicians and other supporting personnel. Special equipment and facilities will also be required.

A national or international program for screwworm control may be only partially successful or could even fail without a strong program of both basic and applied research on the lines of research proposed,

In order to provide for the basic and applied aspects of the research outlined in item 1-4 (exclusive of item 5) funds and facilities as outlined below will be required:

1. Annual recurring program support for personnel, supplies and equipment

GS-13 Research leader	$ 11,005
5 Senior scientists (GS-12)	48,088
5 Junior scientists (GS-7)	28,323
10 Subprofessional, clerical, and wageboard personnel (GS-3 and GS-5)	42,730
Total personnel	$130,146
Equipment, supplies, operations	69,854
Total for continuing program	$200,000

2. Non-recurring support for facilities and special equipment

Office and laboratory, 5000 sq. ft. @ $35 per sq. ft.	$175,000
Special fly rearing building (fly secure)	50,000
Special equipment for irradiation and facilities for irradiation sources	50,000
Special equipment for cytological, biochemical, nutritional, and entomological research	25,000
Total non-recurring	$300,000

The above will not purchase all of the non-recurring items of equipment needed. However, during the first year, it is anticipated that one-fourth of the funds needed for annual program support will be available for additional special equipment.

Methods Development

A successful insect control or eradication program is predicated upon the results of basic research, which must precede or be concurrent with an action program. There is, however, a wide gap between where research ends and large-scale field operations begin. It is necessary, therefore, to bridge the gap between research and control activities by adapting the findings of research to the magnitude and complexity of control or eradication operations. This is especially true of screwworm control or eradication programs where the sterilizing techniques are so new, and where such huge numbers of flies must be reared, sterilized and dispersed over large land areas. There are still many problems to be solved by research and development in order to effectuate an efficient and economical program.

In addition to the needs for the basic research outlined above, there is urgent need for the development and improvement of methods and materials to put the results of research into practical use. Among the more important methods and materials that need attention are:

1. To improve larval rearing vats to provide an even and uniform temperature over the entire area.

2. To improve methods of collecting mature larvae that will reduce labor costs, provide a more favorable environment, and prevent the escape of larvae that will develop into fertile flies and jeopardize control operations.

3. To improve the cobalt-60 irradiation units and/or the loading and unloading mechanisms - for efficiency of operation, elimination of human error, and speed-up operations.

4. To determine the possibility of using larger airplanes flying at higher altitudes - to increase swath-width and carry much larger loads of packaged flies, thereby reducing costs of fly distribution.

5. If the use of larger planes is practicable, to develop larger cartons for irradiated flies, a new packaging machine, and design a new package disperser for such planes.

6. To determine the most favorable environment for larvae to pupate for more uniformity in the time of pupation.

7. To determine the effectiveness of a barrier zone as to width and number of sterile flies to be released - to prevent native flies from migrating into uninfested areas.

Research Background for Screwworm Eradication

The first worker to observe that insects could be sterilized was G. A. Runner, an entomologist of the U. S. Department of Agriculture, who published in the Journal of Agricultural Research in 1916. He found that cigarette beetles infesting tobacco were either killed or sterilized by large doses of x-rays. No practical application was made of Runner's discovery and his work went largely unnoticed.

In 1927 H. J. Muller, a geneticist working at the University of Texas, published in Science that he could change the heredity of fruit flies by treating the males with x-rays. Muller's work attracted the attention of geneticists who were seeking means to induce mutations for studies in heredity. These geneticists found that they could not safely

give more than a few hundred roentgens of irradiation to male fruit flies because higher doses caused such extensive chromosome changes in the sperm of irradiated males that their progeny could not live. These mutations that caused death were referred to in the genetics literature as "dominant lethal mutations." Many geneticists worked with various species of fruit flies, fungus gnats, and parasitic wasps and observed these effects from overdoses of x-rays or gamma rays but no one seemed to consider any practical application for this phenomenon. Those specialists in heredity were more interested in having their organisms survive so that they could study the inheritance of changed characteristics. So the sterilizing effects of radiation were known among this group of specialists who used this knowledge largely to avoid overdosing their experimental insects but no one seemed to consider radiation as a possible tool for insect control.

In 1936 Roy Melvin and R. C. Bushland, working in the Dallas, Texas laboratory of the Entomology Research Division, developed a practical, inexpensive means for mass rearing of screwworm flies in the laboratory, although in nature screwworms can develop only in wounds in living warm-blooded animals. Those entomologists found that larvae could be grown in a laboratory incubator at body temperature on a mixture of ground lean meat, citrated beef blood and water with a little formaldehyde added to retard putrefaction. The only expensive ingredient in this formula was the ground meat and 500 larvae developed in each pound of meat.

In 1938 E. F. Knipling, working with caged screwworm flies noted that the females appeared to mate only one time. He proposed that, if a means for sterilizing laboratory-reared screwworm males could be developed,

it might be practical to produce enough sterilized flies for distribution in nature to outnumber the wild flies and thus have a means for eradicating isolated screwworm populations.

Screwworms were unknown in the Southeast prior to 1933 when they were presumably introduced through shipment of infested cattle into southern Georgia and spread throughout Florida. Efforts to control screwworms in that area by good animal husbandry practices and treatment of wounds with benzol and pine tar oil had greatly reduced infestations during a control program in the years 1935-37. However, screwworms were not eradicated because some breeding persisted in wildlife and neglected domestic animals to maintain the infestation.

Dr. Knipling believed that this residue of flies might be overwhelmed by sterilized insects. If sterilized males outnumbered native males and competed effectively for mates, the majority of the native females would make sterile matings and be unable to reproduce. By maintaining continuous releases of large numbers of sterile insects, each generation of native insects would be further outnumbered so that theoretically within a few generations the mathematical odds against a fertile mating would be so great that eradication would result.

In 1947 entomologists at the Kerrville laboratory were directed to study the mating habits of screwworm flies and to test chemical sterilizing agents. The experiments with chemical sterilizing agents were unsuccessful.

In 1950 Dr. Muller wrote an article in American Scientist in which he mentioned the sterilizing effects on insects of large doses of x-rays and gamma rays. This stimulated investigations of the effects of

radiation on screwworms. Tests with x-rays revéaled that screwworm pupae, after developing for five days at a constant temperature of 80°F., were susceptible to sterilization. A dose of 5000 roentgens of x-rays sterilized both males and females. A dose of 7500 r completely prevented production of eggs in irradiated females. It reduced the sperm count by about half. Eggs fertilized by the irradiated sperm failed to hatch; thence the males were called "sterile". The irradiated flies tolerated about three times the sterilizing dose. This provided an adequate margin of safety to avoid killing the insects in the sterilization procedure. The sterilized flies did not live quite as long as untreated insects, but the sterilized males competed for mates with normal males in cage tests.

Experiments were continued with a small cobalt-60 gamma ray source and workers confirmed the earlier work with x-rays. All the laboratory experiments with caged screwworm flies indicated the possibility of controlling screwworms in nature by outnumbering them with sterilized insects. This work was published by Bushland and Hopkins in the Journal of Economic Entomology in 1951 and 1953.

In 1952 a small research team was transferred to Florida to conduct practical field tests. Screwworms were first reared and sterilized at Kerrville, Texas, and shipped to Florida for release in field experiments. Later a gamma ray source especially made for sterilizing insects was installed at the Orlando, Florida, laboratory. Field observations in Florida confirmed the Texas laboratory work. Sterilized screwworms were released on Sanibel Island off the West Coast of Florida in numbers greater than existed in nature on that island. The natural population of screwworms was greatly reduced but eradication could not be proved because the island

was so close to the mainland that new flies migrated in to lay fertile eggs.

The conclusive experiment was performed in 1954 when screwworms were eradicated from the island of Curacao. Flies were reared and sterilized at Orlando, Florida, and shipped by air freight to Curacao where they were released. It was found that when Curacao was treated twice weekly at the rate of 400 sterilized flies per square mile per week, by distributing the flies in half-mile swaths from an airplane, the native population was outnumbered. During the first month of releases 69% of the egg masses laid by wild flies were infertile (indicating mating with the released males). After four weeks of such releases, when a new generation appeared, the number of wild flies was greatly reduced and the percentage of sterility had increased to about 90%. In another month only a few sterile egg masses could be collected, and the last sterile egg mass was collected after fourteen weeks of releases. Releases were continued for eight more weeks to assure eradication. Screwworms have not reappeared on Curacao. The details of this work were published in the Journal of Economic Entomology in 1955 by Baumhover et al.

For the Curacao work, 170,000 screwworms had to be reared each week. To conduct an eradication campaign in Florida at the same average rate of release would require 50 million flies per week. This made it necessary to conduct more experiments on mass culture methods and large-scale release operations in order to develop practical procedures for a Southeastern eradication program. Therefore, a new insectary was constructed with a capacity of one million larvae per week.

For 20 years the original rearing procedure had been used with little change. The maggots were reared in tubs or trays in cabinets or rooms heated to about 100°F. In cold weather ventilation was reduced to maintain temperatures, and the accumulation of foul odors and ammonia in the air of the building made working conditions difficult.

A. J. Graham and F. H. Dudley devised rearing vats heated from the bottom, and this equipment was refined and improved by C. N. Husman. This change in technique made it possible to rear the larvae in well-ventilated rooms, since the thermostatically equipped vats function independently of the room temperature. The new technique also more closely simulates the conditions in nature where the larvae grow in a warm-blooded host and breathe fresh air. This change to vat rearing made it possible to double the capacity of the pilot plant, so that two million flies could be reared weekly in the same space.

The routine procedure of collecting eggs was to induce oviposition by capturing gravid females in shell vials containing pieces of fresh lean meat and holding them for two hours at 90°- 100°F. This practice became very laborious when thousands of females had to be egged for mass cultures. It was found that flies could be induced to oviposit merely by placing a heated attractant in a cage of flies where the room temperature was 80°F. Later a standard technique was developed for egging large cultures.

The liquid that drains from thawing frozen horse meat or ground beef heart is heated for about two days at 98°F. The products of bacteria growing in this fluid are highly attractive to ovipositing flies. This liquid is used to moisten fresh ground meat, which is placed in an

electrically heated container and inserted in a colony cage when the flies are seven days old. The air temperature is 80° and the oviposition medium is heated to 100°. The gravid females swarm down upon the medium to feed and oviposit, and more than 90% of them lay their eggs within three or four hours.

All the laboratory and field work through the Curacao experiment was performed with a strain of flies that had been reared in Texas field laboratories since 1935 and had been inbred for the first ten years. After 1946 there were introductions of new genes by collecting egg masses from ranch animals, rearing these new collections to the adult stage, and adding the flies to the laboratory breeding colony.

Since the Southeastern infestation had existed as an isolated population since 1933, it seemed that screwworms might have adapted themselves to the subtropical and humid conditions of Florida. If so, the native males might be better fitted to compete in that environment than those of the Texas strain, which originated from a semi-arid region. Therefore, egg masses were collected from natural screwworm cases in Florida and southern Georgia, and a laboratory strain was developed from those collections. Only those flies that lived longest under laboratory conditions were selected for propagation. Also, by confining individual males in cages with 25 females and rearing only those insects from the cages in which the most females were fertilized, a strain was developed in which the males can mate about 17 times.

The longevity and mating vigor of the Florida strain may be partly due to careful selection, but certainly much of the credit must be given to the improved techniques for rearing and maintaining laboratory cultures.

Experimental work was also done on more efficient procedures for packaging and distributing sterilized flies. A standard one-pound frozen food carton was adapted to provide a ventilated paper box with a capacity of 400 flies. Pupae are placed in the box after irradiation, and the boxes are held under controlled temperature and humidity until the adults emerge. The flies are then released from airplanes equipped with motor driven mechanisms which open and release the cartons at a preset rate of delivery.

The 70-curie gamma ray source, which had been entirely satisfactory for sterilizing flies released in previous experiments, did not have the capacity for mass sterilization. M. E. Jefferson, radiological safety officer of the Agricultural Research Service, and J. F. Mullins, of the Instrument Design Section at Beltsville, Maryland, with the cooperation of engineers of Brookhaven National Laboratory, designed and installed at Orlando a 600-curie source which can sterilize 18,000 pupae every seven minutes.

During the summer of 1957 these facilities were used in a large-scale field test, in which the Animal Disease Eradication Division and the Florida Livestock Board also participated, to determine the practical application of the sterilized fly technique for screwworm control over a large area.

A 2,000-square-mile area in Florida in which a screwworm outbreak was occurring, where flies were more numerous than had ever been observed before on Curacao, was treated with about 500 males per square mile per week for ten consecutive weeks. After the area was saturated with sterile flies, hatching records on collected egg masses indicated that

approximately 70% of the native females mated with sterilized males.

Eradication was not attained because this test area was not isolated from surrounding heavily infested territory and there was considerable migration of flies, as evidenced by the collection of sterile egg masses thirty miles away from the release area. However, the fact that 70% of the matings were sterile (a proportion that succeeded on Curacao) during outbreak conditions confirmed the competitive mating of sterilized males. The experience gained in this test was invaluable in making plans for the eradication program in the Southeast.

In addition to the research on screwworm sterilization, the Entomology Research Division made important progress on the development of screwworm insecticides. As a result of this research the insecticides now recommended for the treatment of screwworm infestations were developed. The first recommended treatment was benzol and pine tar oil, then Smear 62 and Smear EQ 335. The effectiveness of Co-Ral (Bayer 21/199) as a screwworm killer and as a protectant of wounds against infestations were determined by these workers. The use of Co-Ral sprays and dusts, in connection with field operations and regulatory procedures in the screwworm eradication program, is based upon the research and recommendations of the Entomology Research Division.

LIVESTOCK NUMBERS, BY SPECIES, BY STATES

From U.S.D.A. Agricultural Statistics - 1958

State	Cattle	Sheep	Swine	Horses & Mules	Goats *	T O T A L
Arizona	943,000	419,000	34,000	57,000	52,000	1,305,000
California	3,733,000	1,616,000	442,000	71,000	6,000	5,868,000
New Mexico	1,056,000	1,172,000	35,000	59,000	49,000	2,371,000
Louisiana	1,883,000	95,000	386,000	109,000	- - -	2,473,000
Texas	7,736,000	4,700,000	908,000	242,000	3,062,000	16,648,000
Totals	15,351,000	8,002,000	1,805,000	538,000	3,169,000	28,865,000

*Number of goats clipped

LIVESTOCK VALUES, BY SPECIES, BY STATES

From U.S.D.A. Agricultural Statistics - 1958

State	Cattle	Sheep	Swine	Horses and Mules	Goats *	T O T A L
Arizona	$ 103,730,000	$ 6,914,000	$ 925,000	$6,498,000	$ 158,000	$ 118,225,000
California	537,552,000	34,744,000	12,641,000	8,591,000	24,000	593,552,000
New Mexico	116,160,000	23,674,000	878,000	4,071,000	202,000	144,985,000
Louisiana	156,289,000	1,102,000	8,067,000	6,540,000	- - -	171,998,000
Texas	812,280,000	82,230,000	22,972,000	19,118,000	13,432,000	995,052,000
Totals	$1,726,011,000	$148,684,000	$45,483,000	$44,818,000	$18,816,000	$1,983,812,000

*Value of sales of mohair

Control and Eradication Programs

When, and if, it is considered advisable to initiate a screwworm control or eradication program in the Southwestern United States and Mexico, it would be desirable to start on a comparatively small scale and gradually expand operations as results are evaluated and techniques improved. As discussed above, under "Eradication" and "Research and Development", there are some unsolved problems concerned with the sterile fly method of control which may interfere with the successful operation of an extensive program in the Southwest. An exploratory or demonstration program would serve as a proving ground for the methods and materials now available, determine the feasibility of an expanded program, and, very probably, give considerable screwworm control in the treated area. Concurrent research and methods development would contribute improved operational techniques.

The same operational procedures now being used in the Southeast should be projected into an initial program in the Southwest and modified from time to time to fit conditions in that area. Therefore, the cost of operating the program in the Southeast is used as a basis for estimating the cost of programs in the Southwest. These estimated costs could vary considerably in the different areas. Several plans for a screwworm eradication program are outlined below. (See tabulated data on page 38.)

Plan 1 - This plan provides for the dispersal of sterile flies over an area of 40,000 square miles, 24,000 square miles in Texas and 16,000 square miles in Mexico (Fig. 57). At the rate of 500 sterile male flies per square mile per week, this program will require fly rearing facilities

to produce 40 million flies per week. The cost of the building and equipment will approximate $1,250,000. Operation of the fly rearing establishment, airplane dispersal of flies, and field work will approximate $4 million annually. The cost of operating the inspection stations along the Texas-Mexican border is estimated at $250,000 annually. Total cost the first year will be approximately $5,500,000, and subsequent annual cost $4,250,000.

This program will help determine the feasibility of a control or eradication program, the number of sterile male flies required per square mile per week to effectuate control; the effectiveness of a barrier zone, i.e., the width of a barrier and number of sterile flies needed to prevent the infiltration of fertile flies into the screwworm-free area; and will serve as a basis for more accurately determining the cost of an expanded program. If this program is successful, it may be possible to reduce the number of flies released per square mile per week and thereby expand the size of the treated area.

Plan 2 - This is an extension of Plan 1, covering 80,000 square miles, and would include 60,000 square miles in Texas and 20,000 square miles in Mexico (Fig. 58). It includes all of the average screwworm overwintering area in Texas east of Terrell County, and a 50 mile buffer zone in Mexico. This plan would give screwworm control over a greater area in Texas and, possibly, give more accurate information to determine the effectiveness of a buffer zone.

The cost of the building and equipment to produce 80 million flies per week will approximate $2,100,000; operation of the fly rearing establishment, airplane dispersal of flies and field work $7,600,000 and the

maintenance of inspection stations $300,000. Total cost the first year will be $10 million, and subsequent annual cost $7,900,000.

Plan 3 - The extent of the area in this plan includes all that covered in Plan 2 plus the overwintering area in west Texas, the Rio Grande Valley in New Mexico, and the extension of the 50-mile zone in Mexico to southern New Mexico (Fig. 59). This is a total of 160,000 square miles and includes 70,000 square miles in Texas, 34,000 in New Mexico, and 56,000 in Mexico. This program, if successful, would eliminate the screwworm in Texas and prevent reinfestation from the south and west. Such an operation would require two fly-rearing buildings, each of a capacity of 80 million flies per week. It provides for the establishment of screwworm inspection stations in New Mexico, along the highways crossing the mountain range east of the Rio Grande River, to prevent the movements of infested, eastbound livestock from entering the eradication area.

The cost of two buildings and equipment will approximate $4,200,000; operation of the fly-rearing establishments, dispersal of flies, and field work $15,200,000; and maintenance of inspection stations $800,000. Total cost the first year will be $20 million, and subsequent annual cost $16 million.

Plan 4 - The area covered by this plan would include all the average overwintering areas in Texas, Arizona, and California; a 50-mile barrier zone in Mexico extending from the Gulf of Mexico to the Pacific Ocean; and a portion of Baja California (Fig. 60). The area totals 240,000 square miles and includes 70,000 square miles in Texas, 1,000 in New Mexico, 34,000 in Arizona, 46,000 in California, and 89,000 in Mexico. This operation would require three fly-rearing establishments, each with

a capacity of 30 million flies per week. It also provides for maintaining screwworm inspection stations along the entire Mexican border.

The cost of the three buildings and equipment will approximate $6,300,000; operation of fly-rearing establishments, dispersal of flies, and the field work - $22,500,000; and maintenance of inspection stations $700,000. Total cost the first year will be $29,800,000, and subsequent annual cost $23,500,000.

Plan 5 - This plan includes the entire area covered in Plan 4 (Figure 60) plus the States of Coahuila, Nuevo Leon, and Tamaulipas in Mexico (Fig. 61 Area A). This area totals 151,000 square miles in the United States and 169,000 square miles in Mexico. The operation will require the construction of four fly-rearing establishments at a total cost of $8,400,000. Cost of operating the fly-rearing facility, airplane disposal of flies, and field work will approximate $30,400,000. Cost of operating inspection stations along the southern border of this entire area is estimated at $1 million. Total cost the first year will be $39,800,000, and subsequent annual cost $31,400,000.

Plan 6 - The area covered in this plan is all of the area included in Plan 3 (Fig. 59) plus the States of Coahuila, Nuevo Leon, and Tamaulipas, in Mexico (Fig. 61 Area A). The total area is 248,000 square miles, of which 104,000 are in the United States and 144,000 in Mexico. Three fly-rearing establishments will cost $6,300,000. Operational costs of fly-rearing facilities, airplane dispersal of flies, and field work will approximate $22,800,000; and the maintenance of inspection stations $900,000. Total cost the first year will be $29,900,000, and subsequent annual cost $23,600,000.

Plan 7 - This plan includes all the area covered in Plan 4 (Fig. 60) plus the States of Coahuila, Nuevo Leon, Tamaulipis, Chihuahua, Sonora, and Baja California Norte in Mexico (Fig. 61 Area A & B). This totals 458,000 square miles of which 151,000 are in the United States and 307,000 in Mexico. Total cost the first year for buildings, equipment, fly-rearing and field operations, and inspection stations will approximate $49,500,000, and subsequent annual cost $39,000,000.

Plans 8, 9, 10 and 11 are extensions of Plan 7 with the additions of areas C, D, E and F respectively (Fig. 61). (See tabulated data on page 38 for estimated costs.)

At the successful completion of Plan 11 a screwworm barrier zone would be established across the Isthmus of Mexico. The barrier would be established by releasing sterile male flies in sufficient numbers and over an area of sufficient width to prevent the northward migration of fertile flies into the screwworm-free area. The barrier would be supplemented by the enforcement of regulations designed to prevent the movement of infested livestock into the fly-free area. The annual cost of operating this activity will approximate $4 million.

DATA ON SCREWWORM ERADICATION PLANS

Plan No.	Square Miles: United States	Square Miles: Mexico	ESTIMATED COSTS: Buildings and Equipment	ESTIMATED COSTS: Fly Rearing and Field Operations	ESTIMATED COSTS: Inspection Stations	ESTIMATED COSTS: TOTAL 1st Year	ESTIMATED COSTS: Annual Operations
1	24,000	16,000	$1,250,000	$4,000,000	$250,000	$5,500,000	$4,250,000
2	60,000	20,000	2,100,000	7,600,000	300,000	10,000,000	7,900,000
3	104,000	56,000	4,200,000	15,200,000	800,000	20,200,000	16,000,000
4	151,000	89,000	6,300,000	22,800,000	700,000	29,800,000	23,500,000
5	151,000	169,000	8,400,000	30,400,000	1,000,000	39,800,000	31,400,000
6	104,000	144,000	6,300,000	22,800,000	900,000	29,900,000	23,600,000
7	151,000	307,000	10,500,000	38,000,000	1,000,000	49,500,000	39,000,000
8	151,000	433,000	12,600,000	45,600,000	1,000,000	59,200,000	46,600,000
9	151,000	503,000	14,700,000	53,200,000	800,000	68,700,000	54,000,000
10	151,000	590,500	16,800,000	60,800,000	800,000	78,400,000	61,600,000
11	151,000	677,000	18,900,000	68,400,000	750,000	88,050,000	69,150,000

SCREWWORM INFESTATION

Arizona, California, Louisiana, New Mexico, Texas

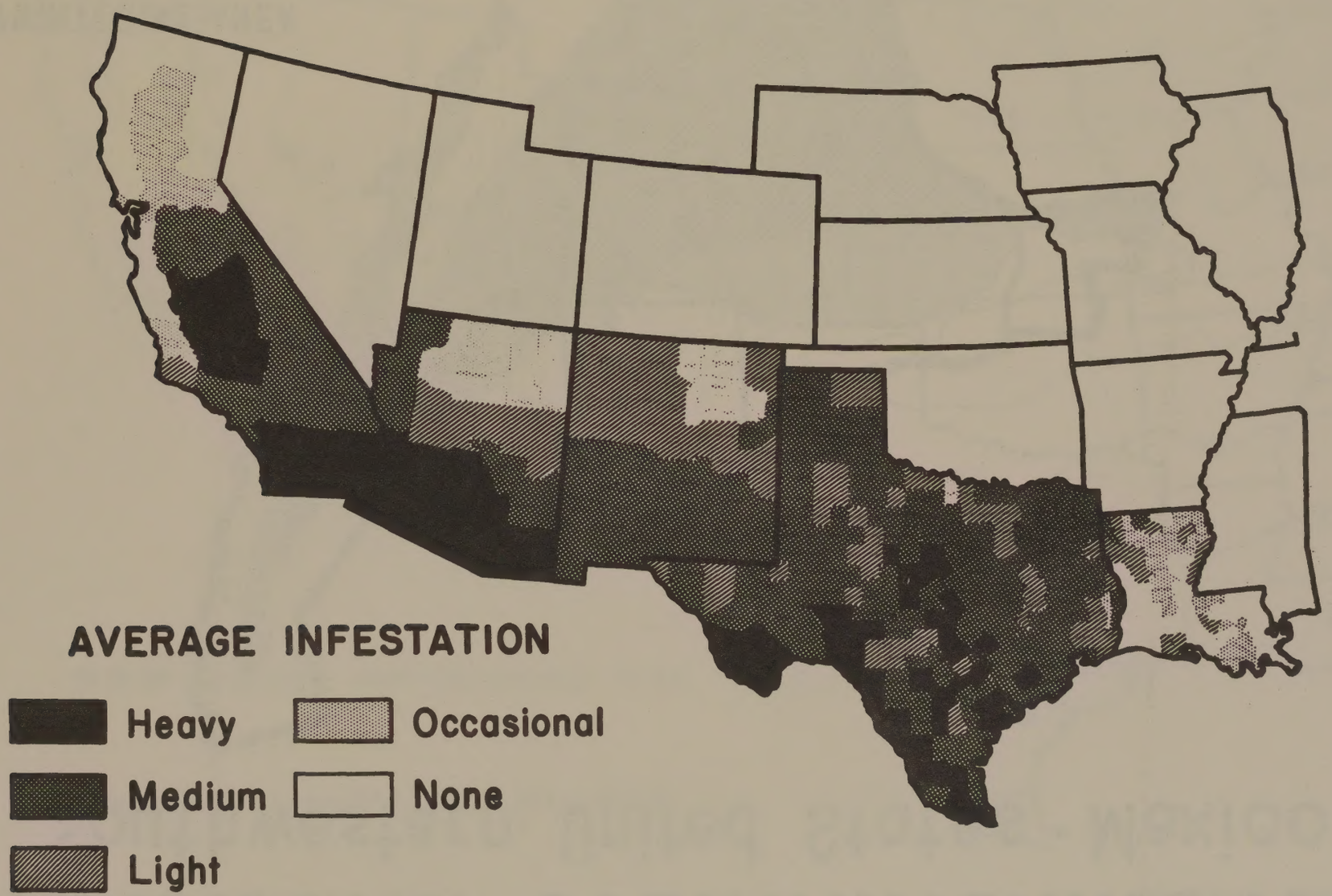


FIGURE 1

U.S. DEPARTMENT OF AGRICULTURE

AGRICULTURAL RESEARCH SERVICE

SCREWWORM OVERWINTERING AREA

Southwestern United States - Mexico

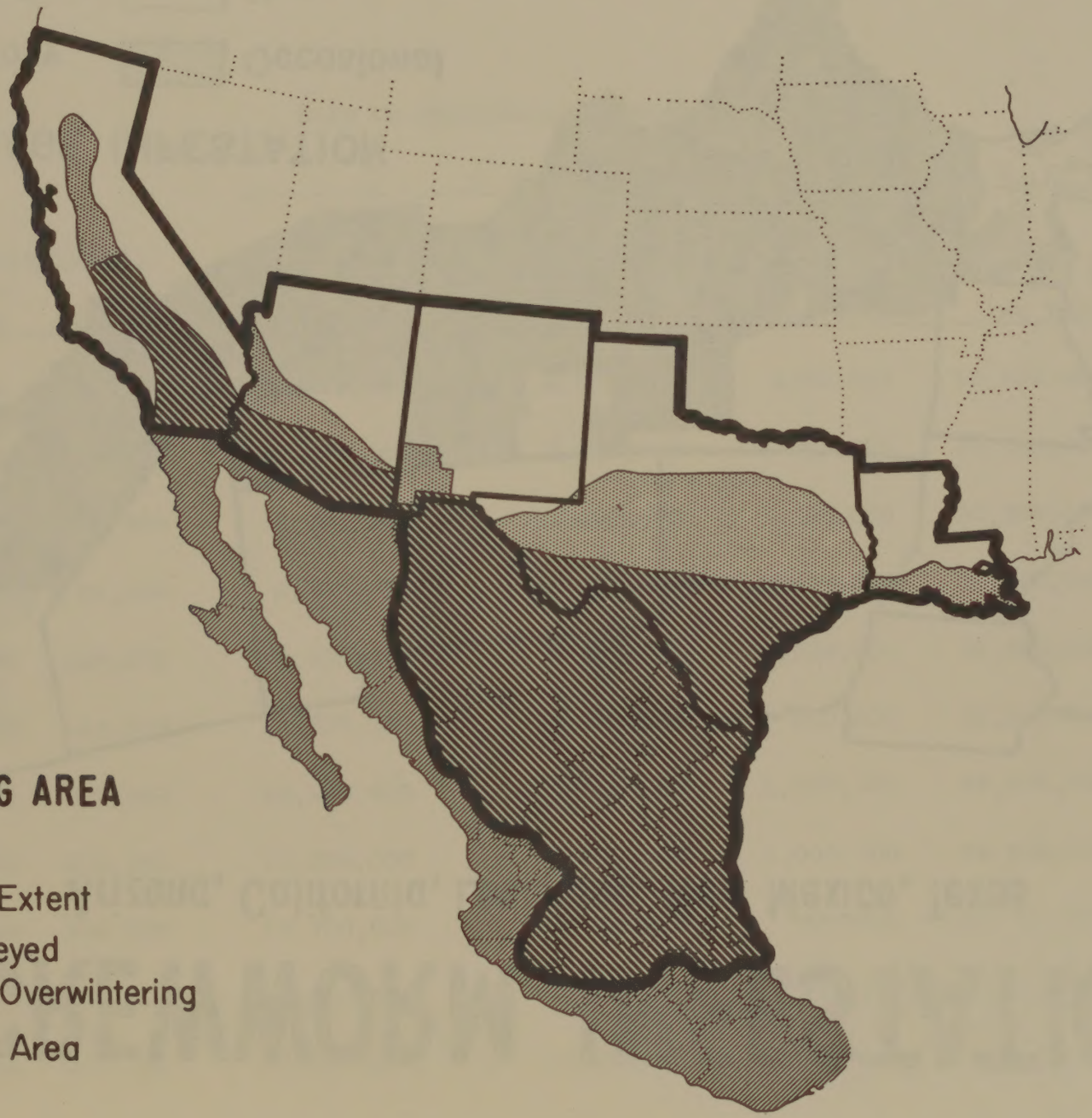


FIGURE 2

SCREWWORM HOSTS

Wild and Domestic Animals

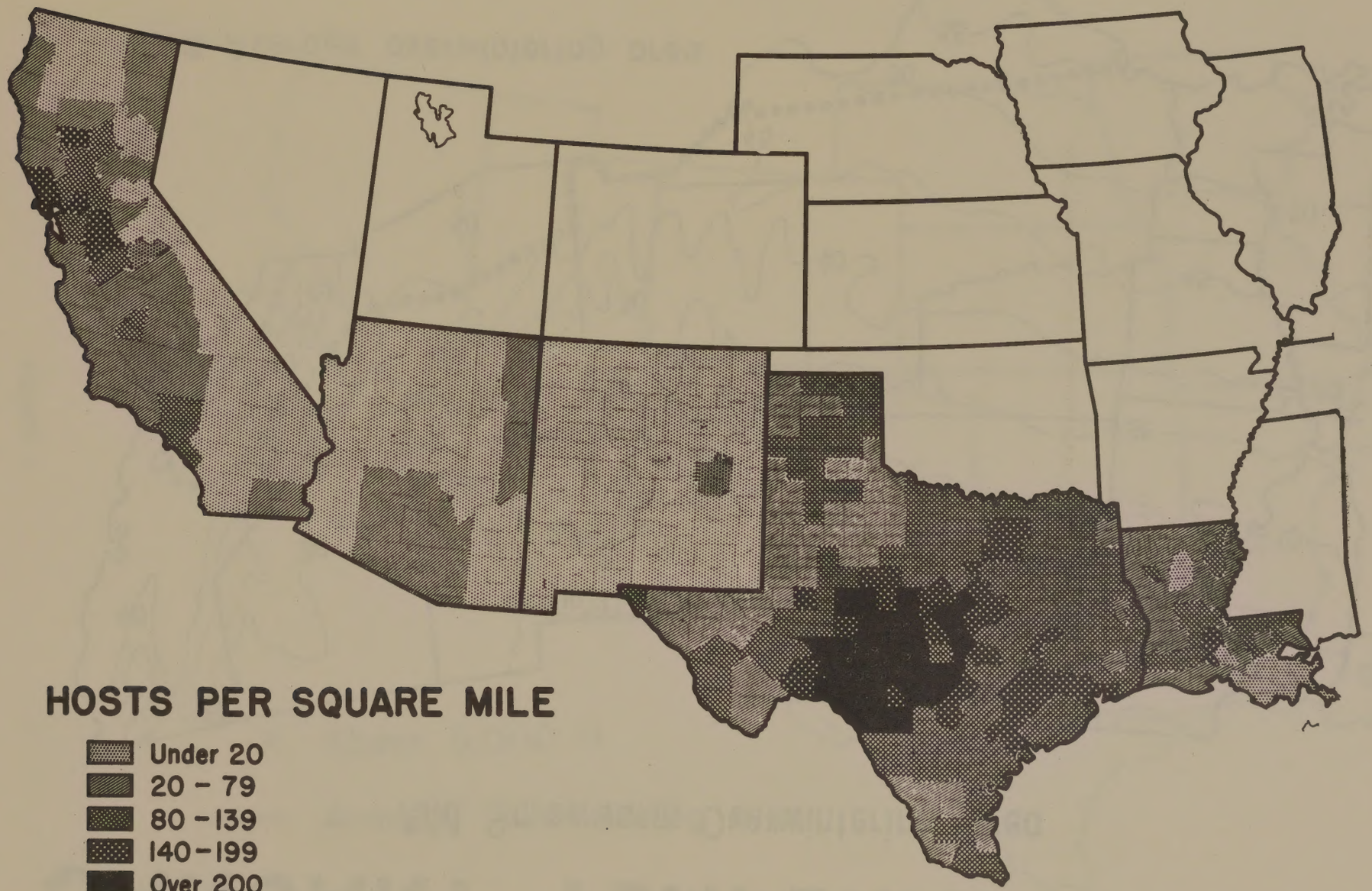


FIGURE 3

U.S. DEPARTMENT OF AGRICULTURE

AGRICULTURAL RESEARCH SERVICE

JANUARY TEMPERATURE °F

And Screwworm Overwintering Area

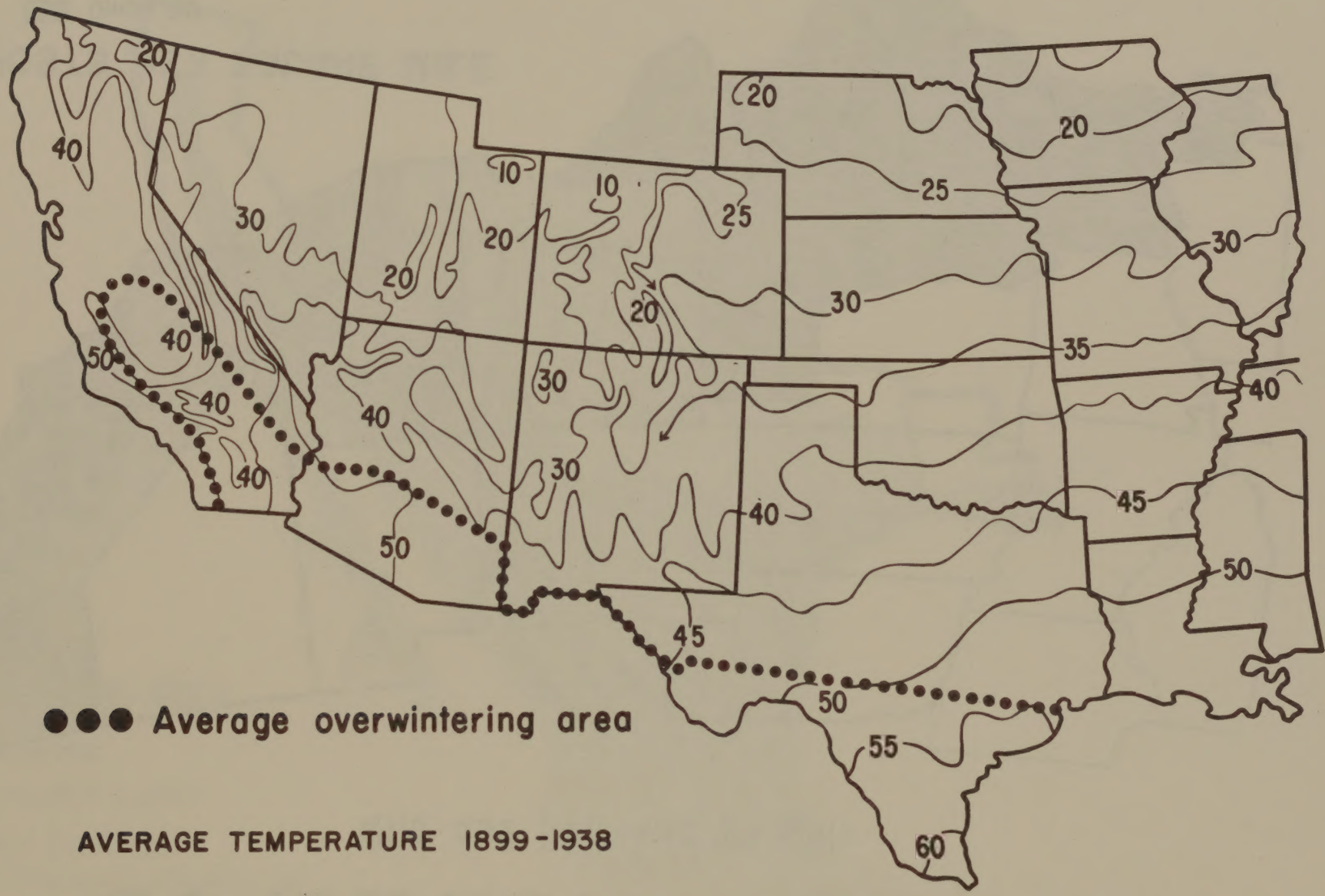


FIGURE 4

U. S. DEPARTMENT OF AGRICULTURE

AGRICULTURAL RESEARCH SERVICE

ALTITUDES ABOVE 6,000 FT.

Within Screwworm Overwintering Area

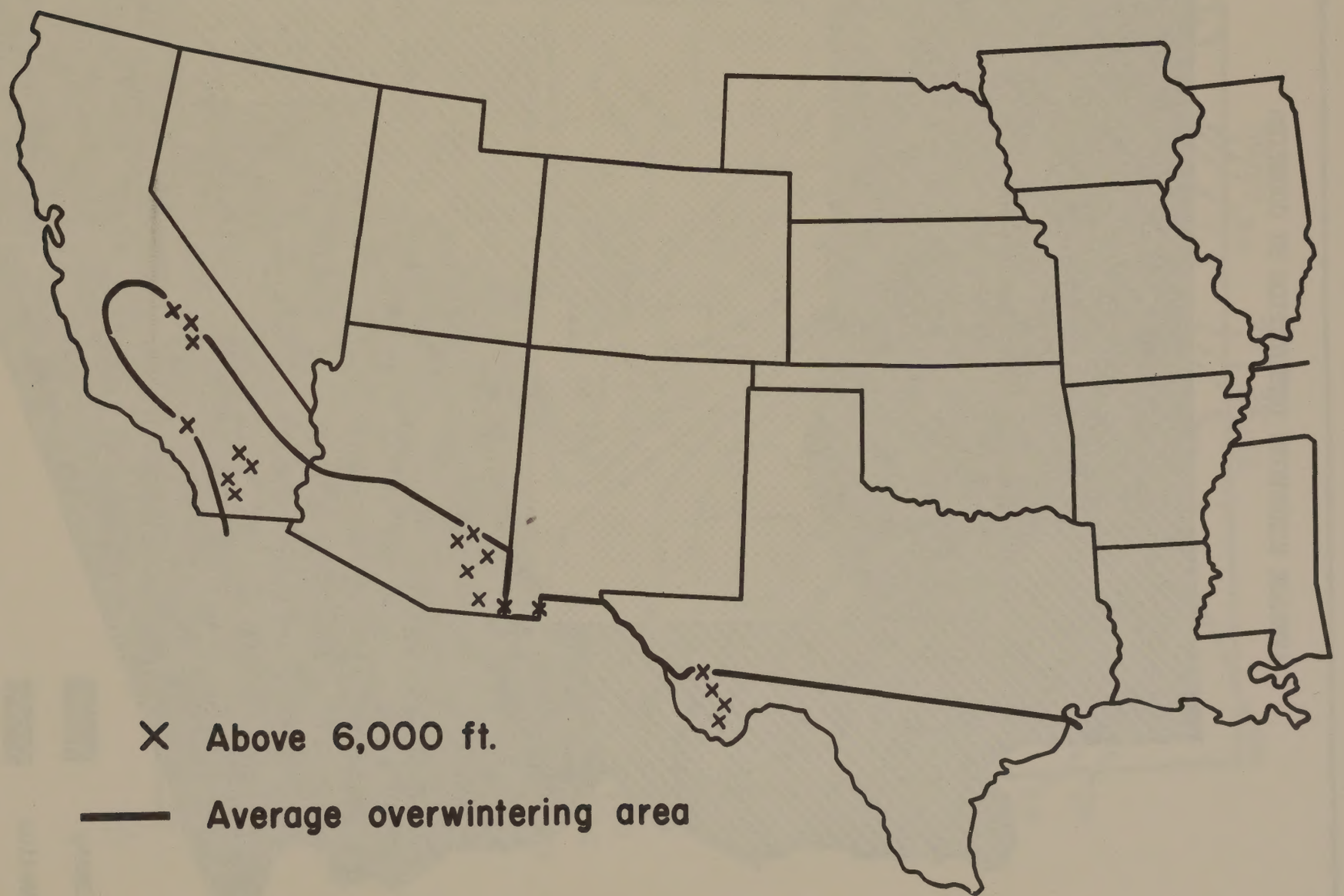
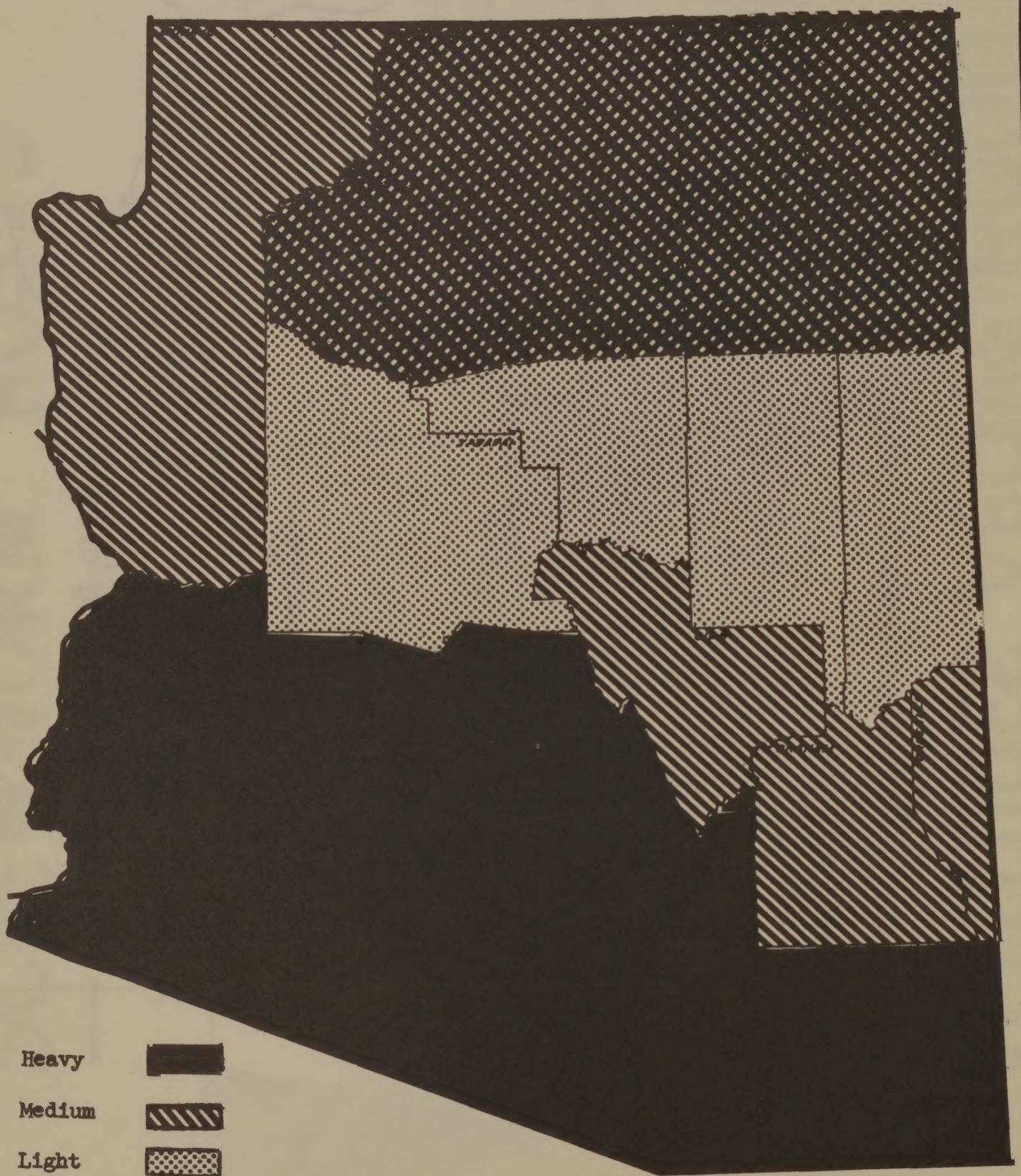


FIGURE 5

U.S. DEPARTMENT OF AGRICULTURE

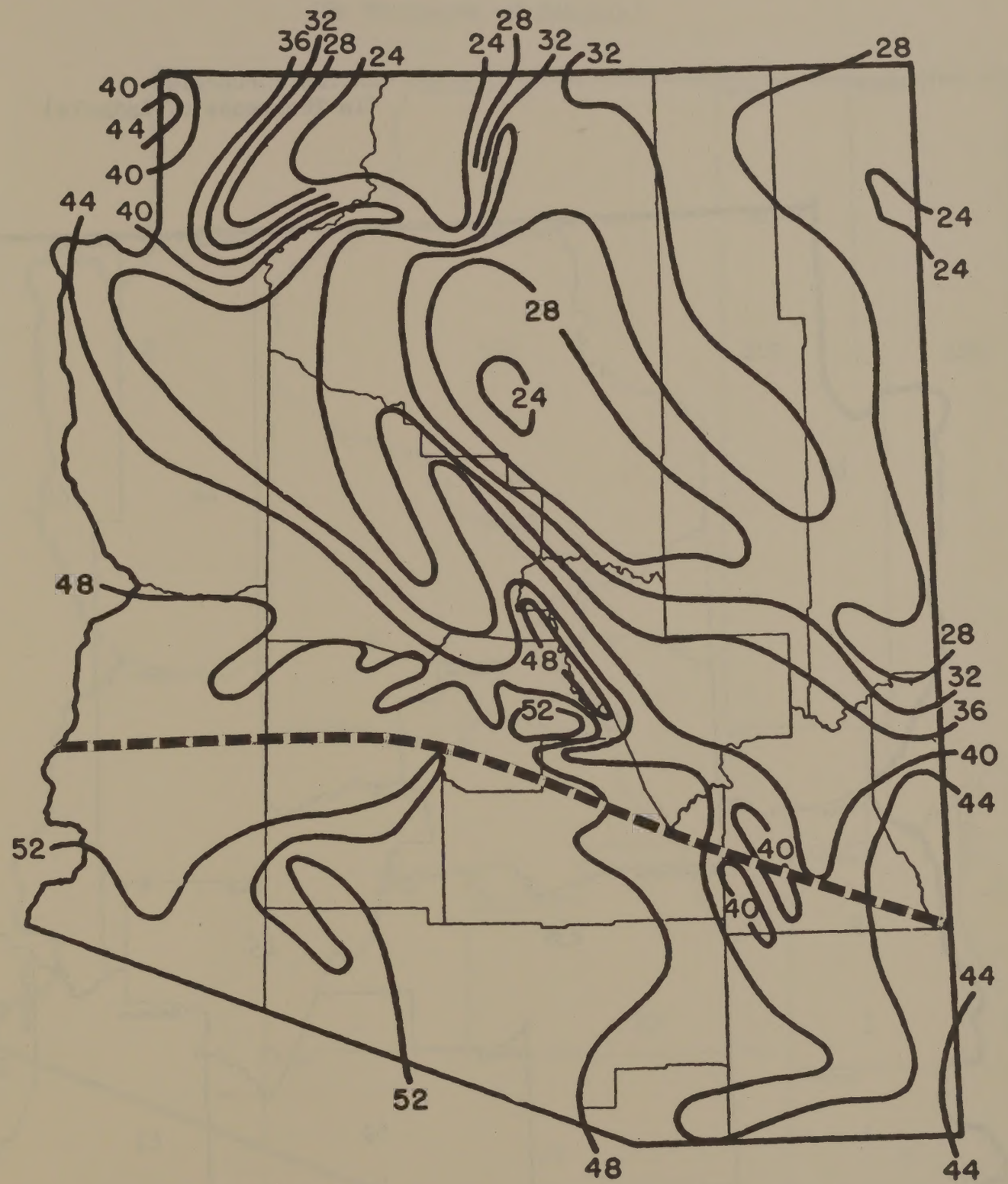
AGRICULTURAL RESEARCH SERVICE

AVERAGE SCREWWORM INFESTATION BY COUNTIES



ARIZONA

FIGURE 6



ARIZONA

AVERAGE JANUARY TEMPERATURE

▬ ▬ ▬ ▬ Northern Limits of Average Overwintering Area

FIGURE 7

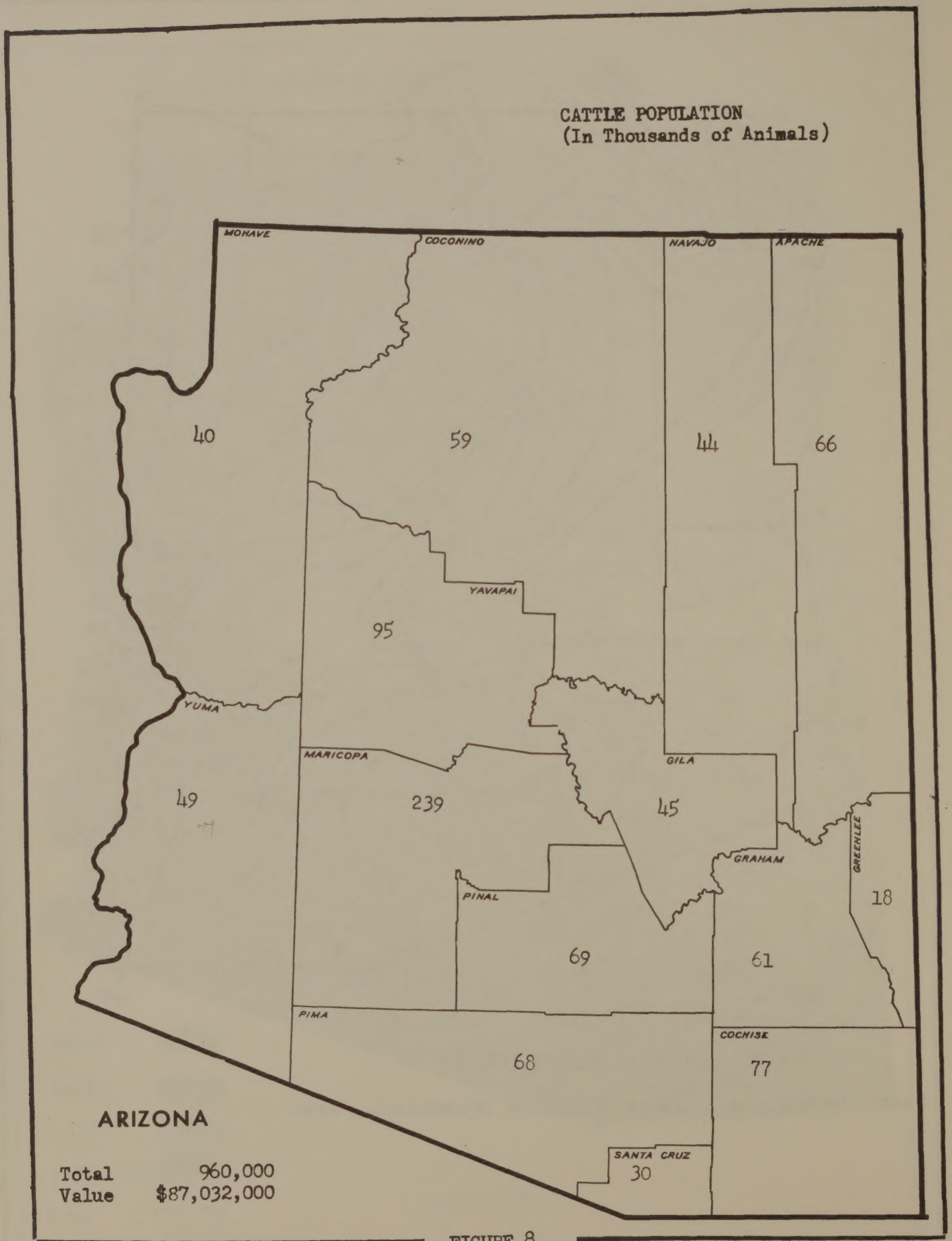
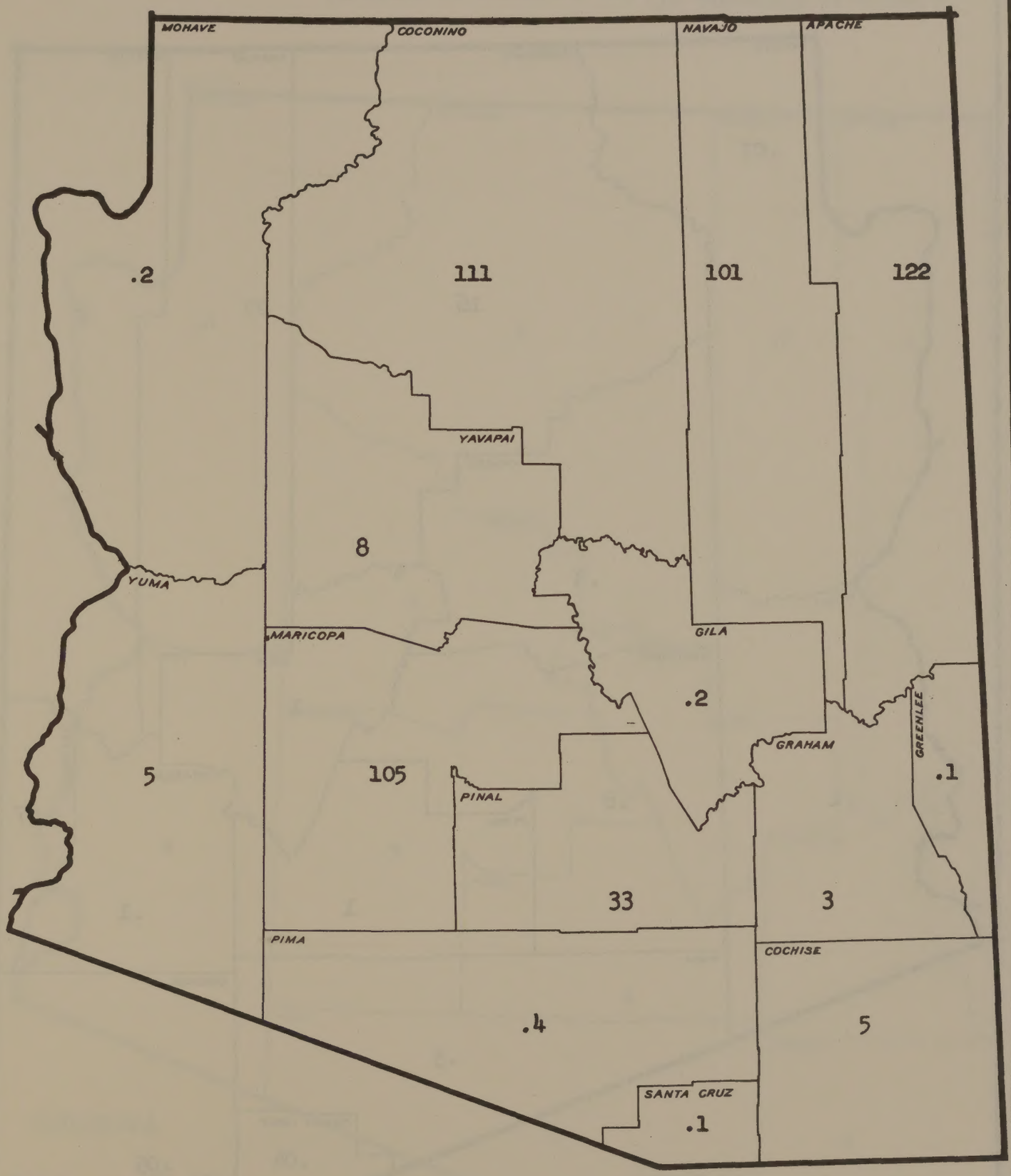

CATTLE POPULATION
(In Thousands of Animals)
MOHAVE
COCONINO
NAVAJO
APACHE
40
59
44
66
YAVAPAI
95
YUMA
MARICOPA
GILA
49
239
45
GRAHAM
GREENLEE
PINAL
18
69
61
PIMA
COCHISE
68
77
SANTA CRUZ
30
ARIZONA
Total 960,000
Value $87,032,000

FIGURE 8

SHEEP POPULATION
(In Thousands of Animals)

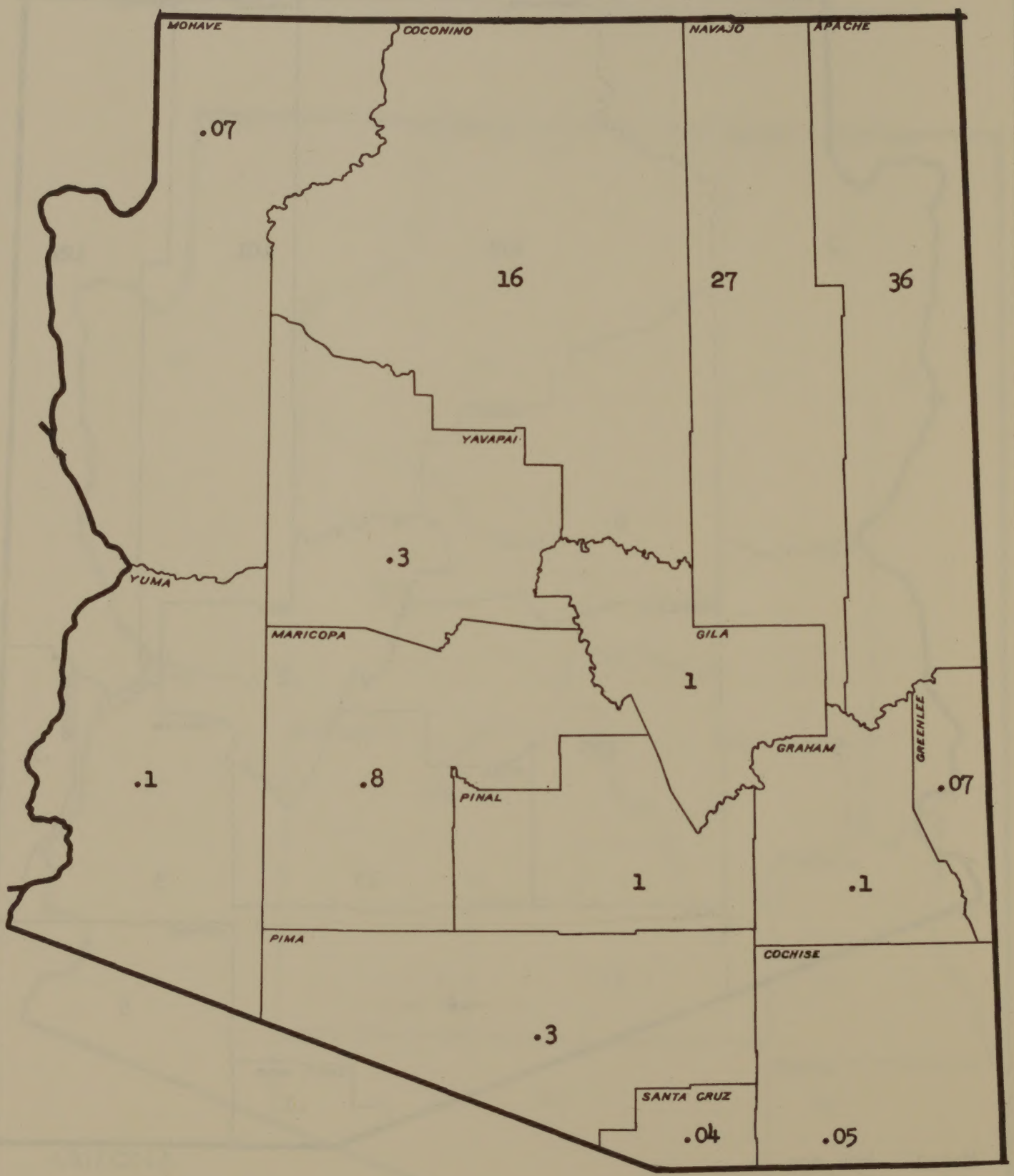


Total 494,000
Value $6,077,000

ARIZONA

FIGURE 9

GOAT POPULATION
(In Thousands of Animals)



Total 82,830
Value $92,000

ARIZONA

FIGURE 10

SWINE POPULATION
(In Thousands of Animals)

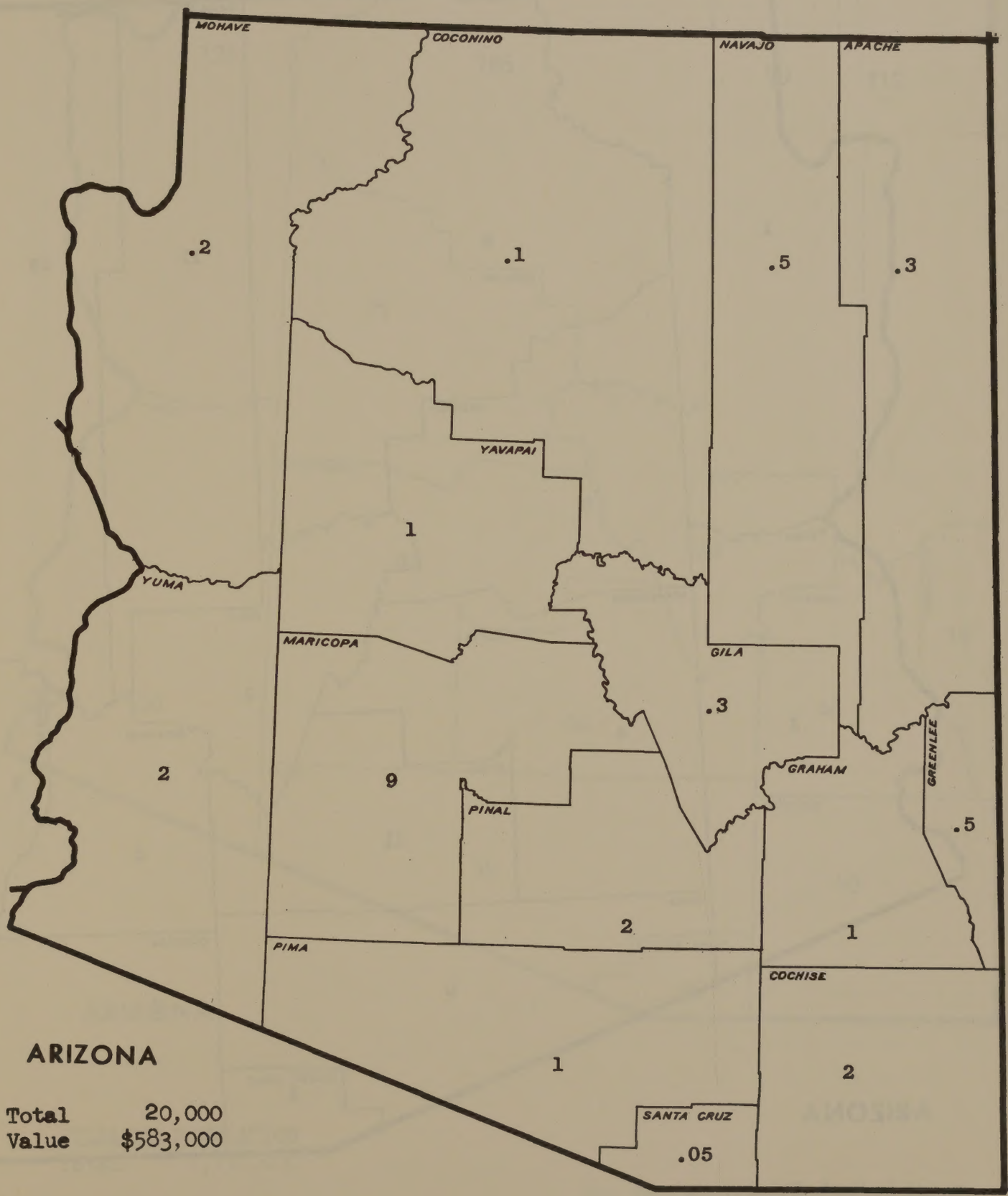
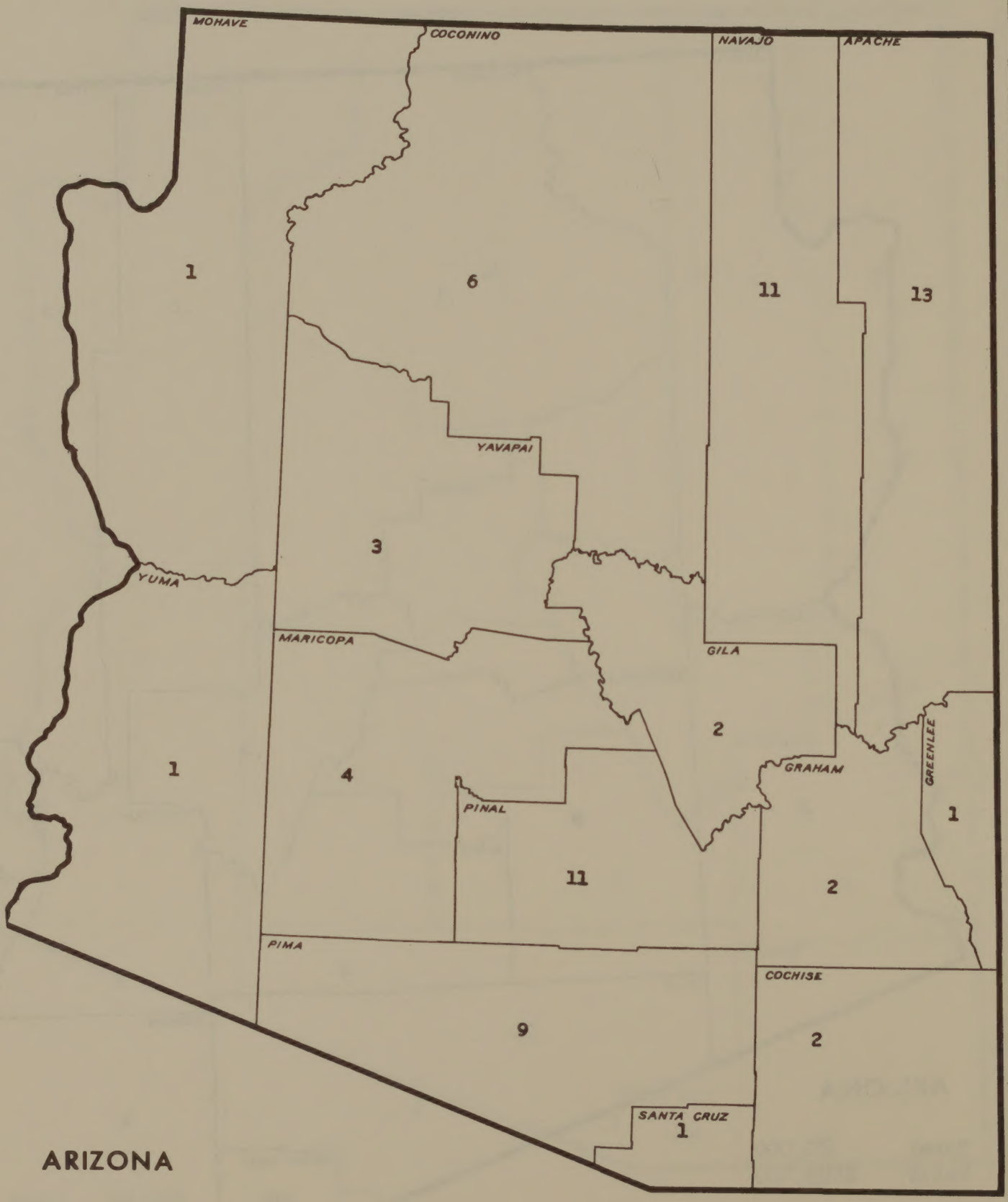


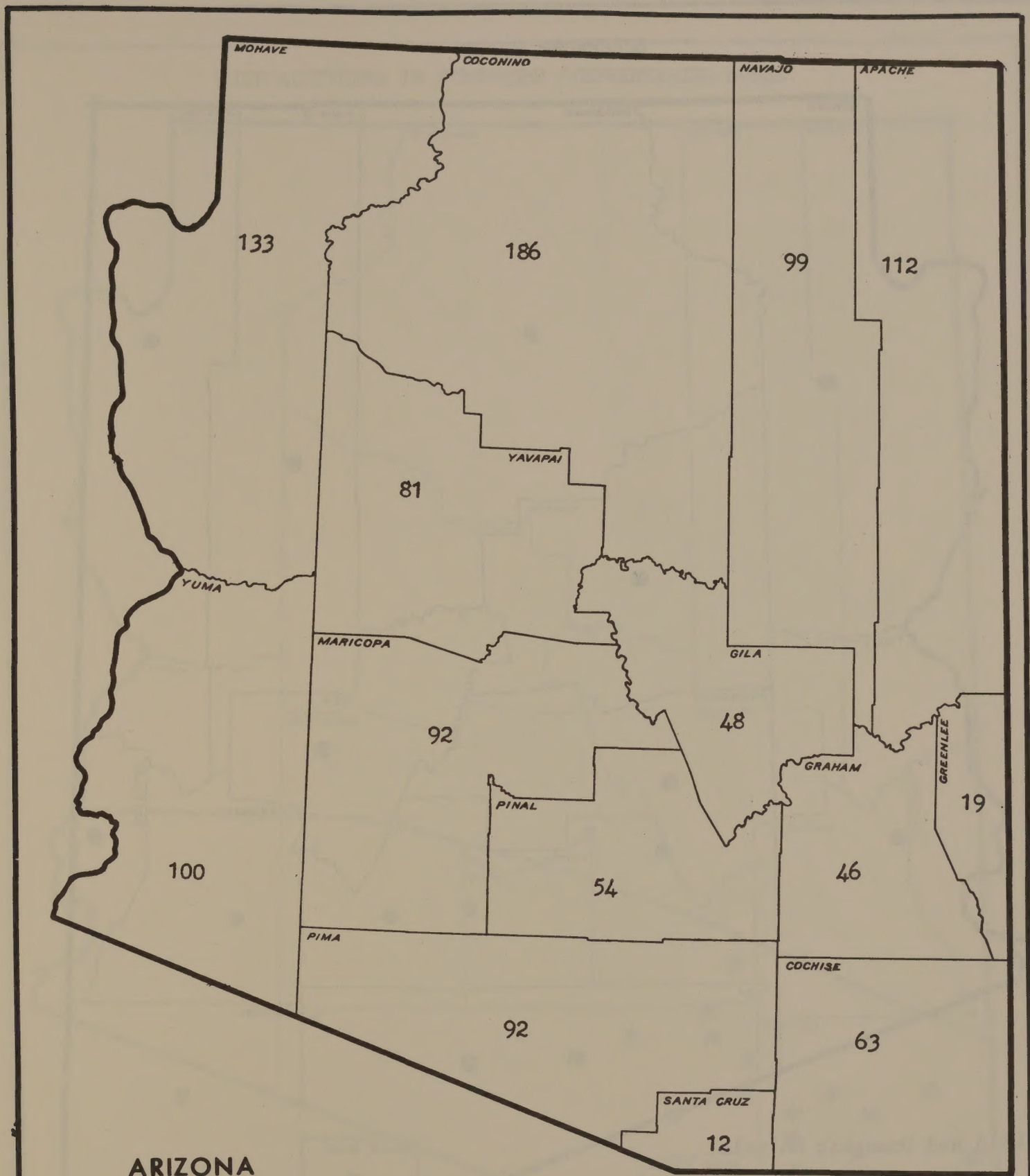
FIGURE 11

HORSE AND MULE POPULATION
(In Thousands of Animals)



Total	67,000
Value	$5,605,000

FIGURE 12



WILDLIFE POPULATION
Total 1,137,000

(In Thousands of Animals)

FIGURE 13

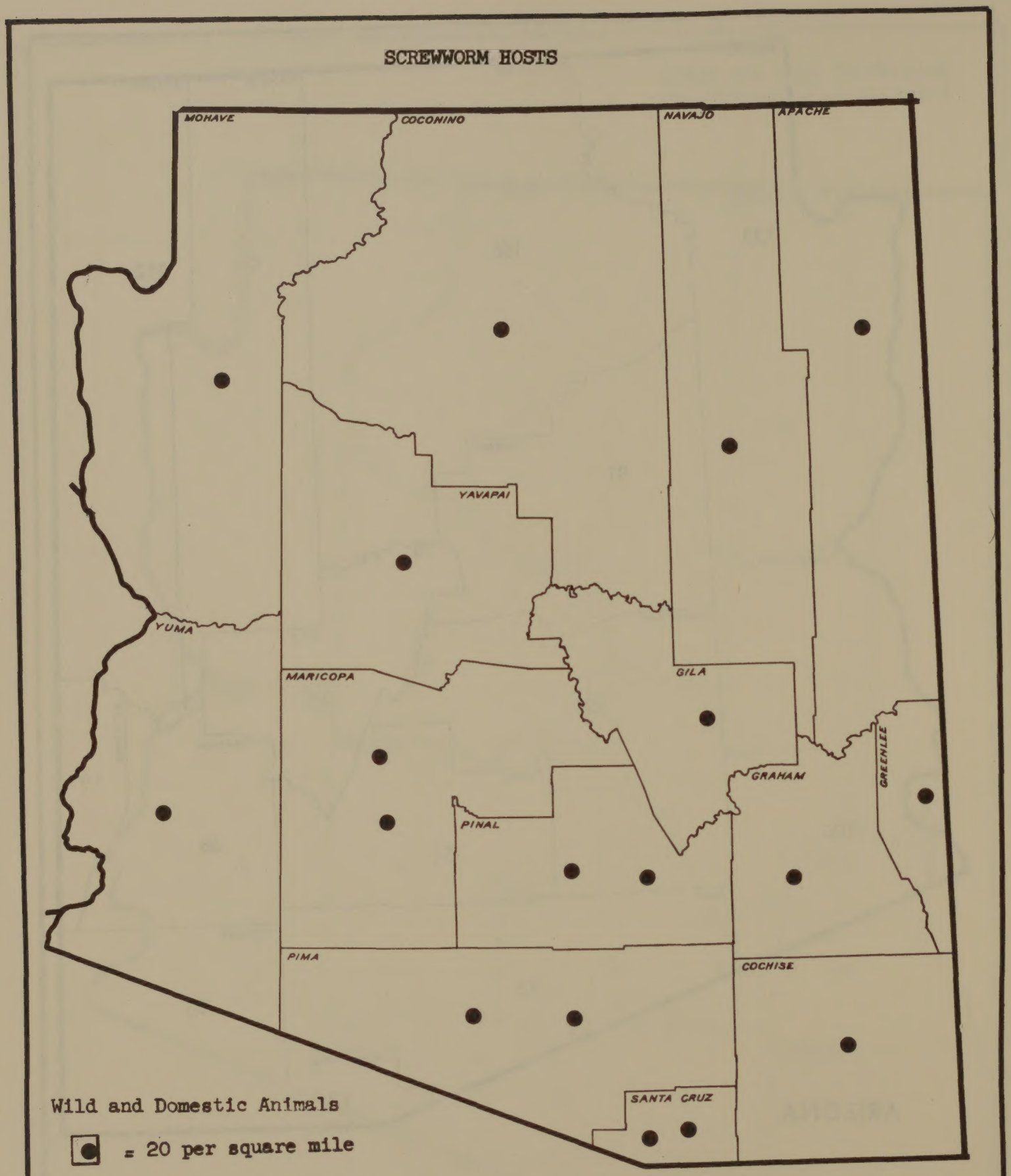
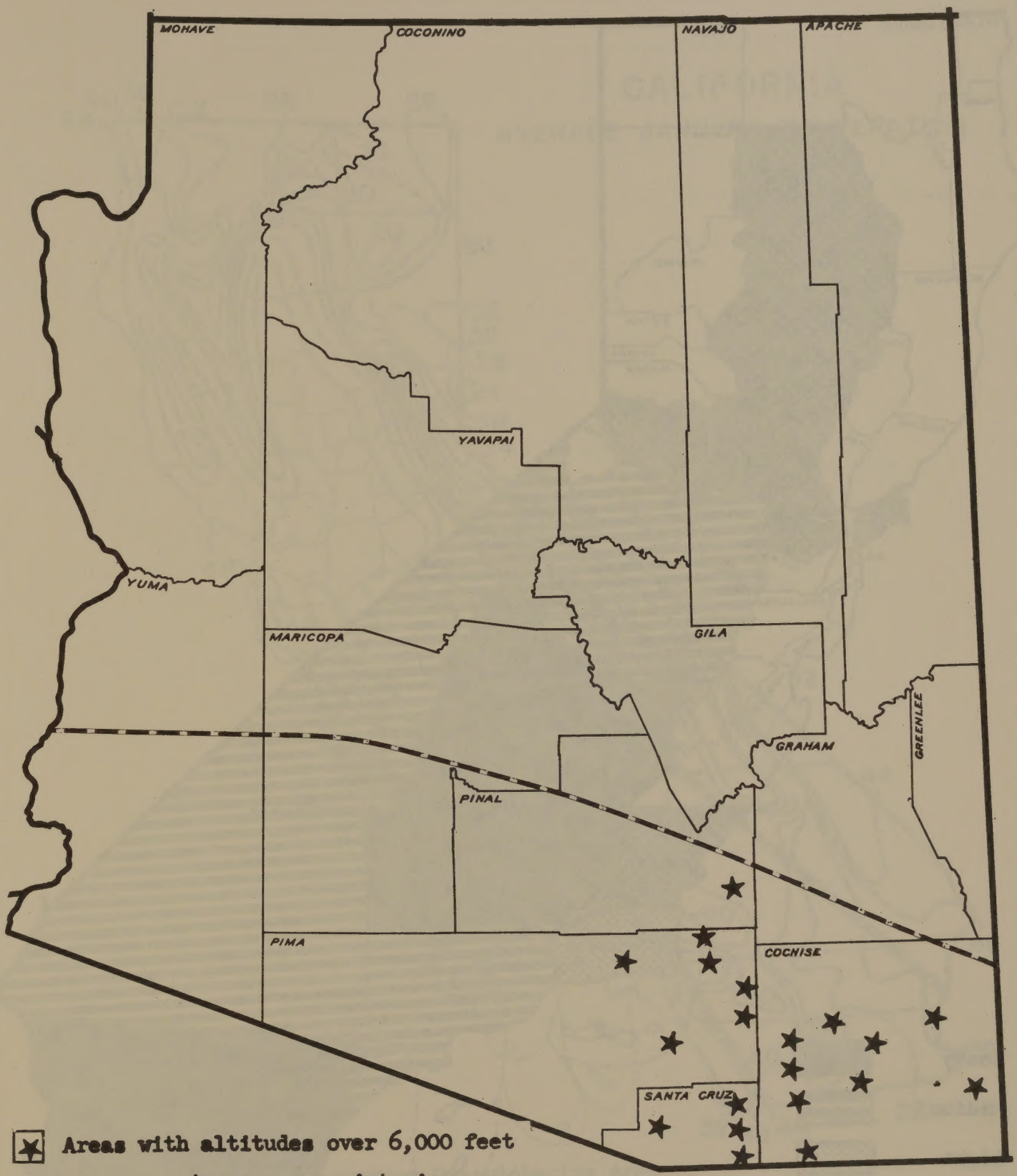

SCREWWORM HOSTS
MOHAVE
COCONINO
NAVAJO
APACHE
YAVAPAI
YUMA
MARICOPA
GILA
GRAHAM
GREENLEE
PINAL
PIMA
COCHISE
SANTA CRUZ
Wild and Domestic Animals
= 20 per square mile
ARIZONA

FIGURE 14

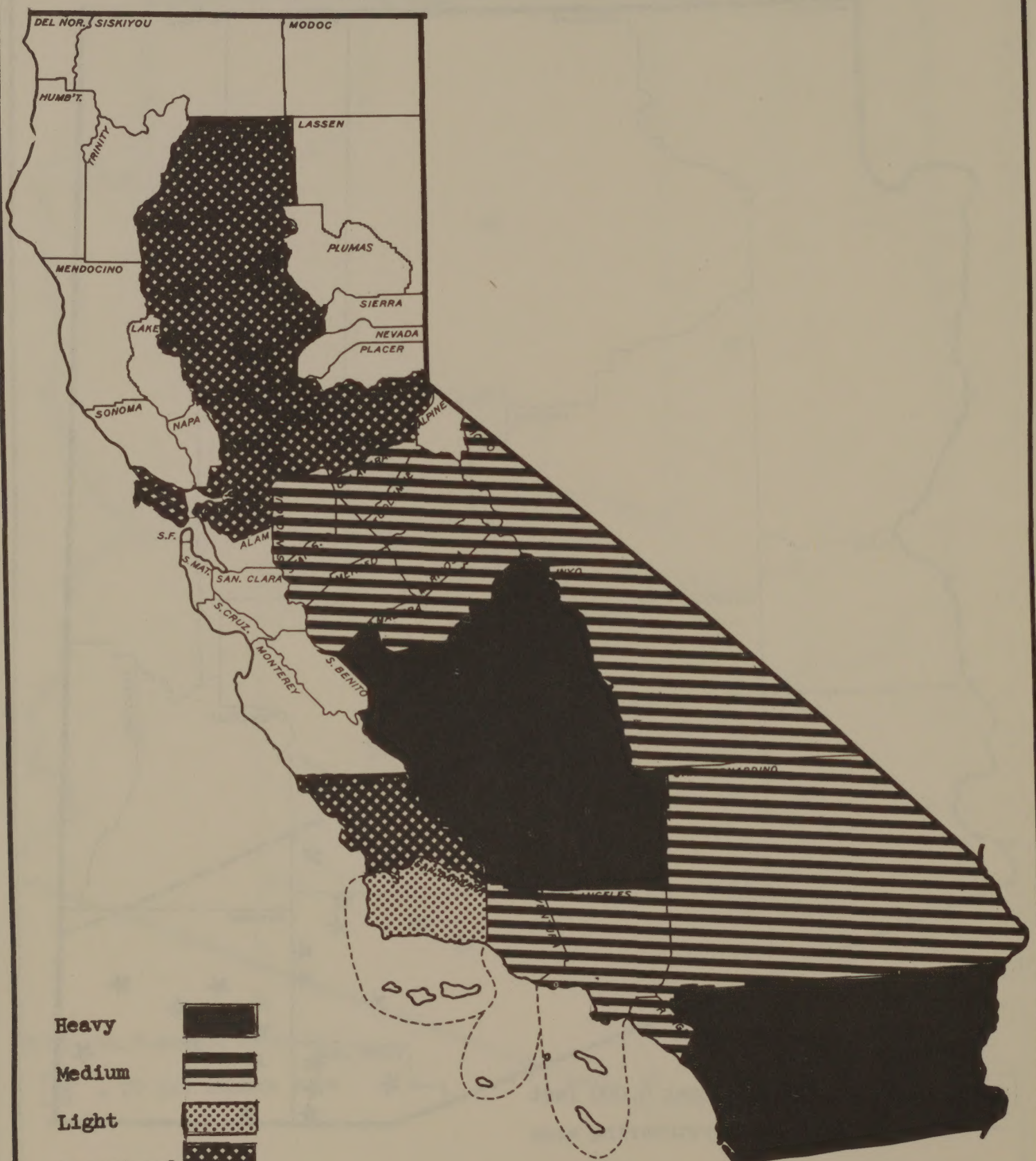
HIGH ALTITUDES IN SCREWWORM OVERWINTERING AREAS



ARIZONA

FIGURE 15

AVERAGE SCREWWORM INFESTATION BY COUNTIES



CALIFORNIA

FIGURE 16

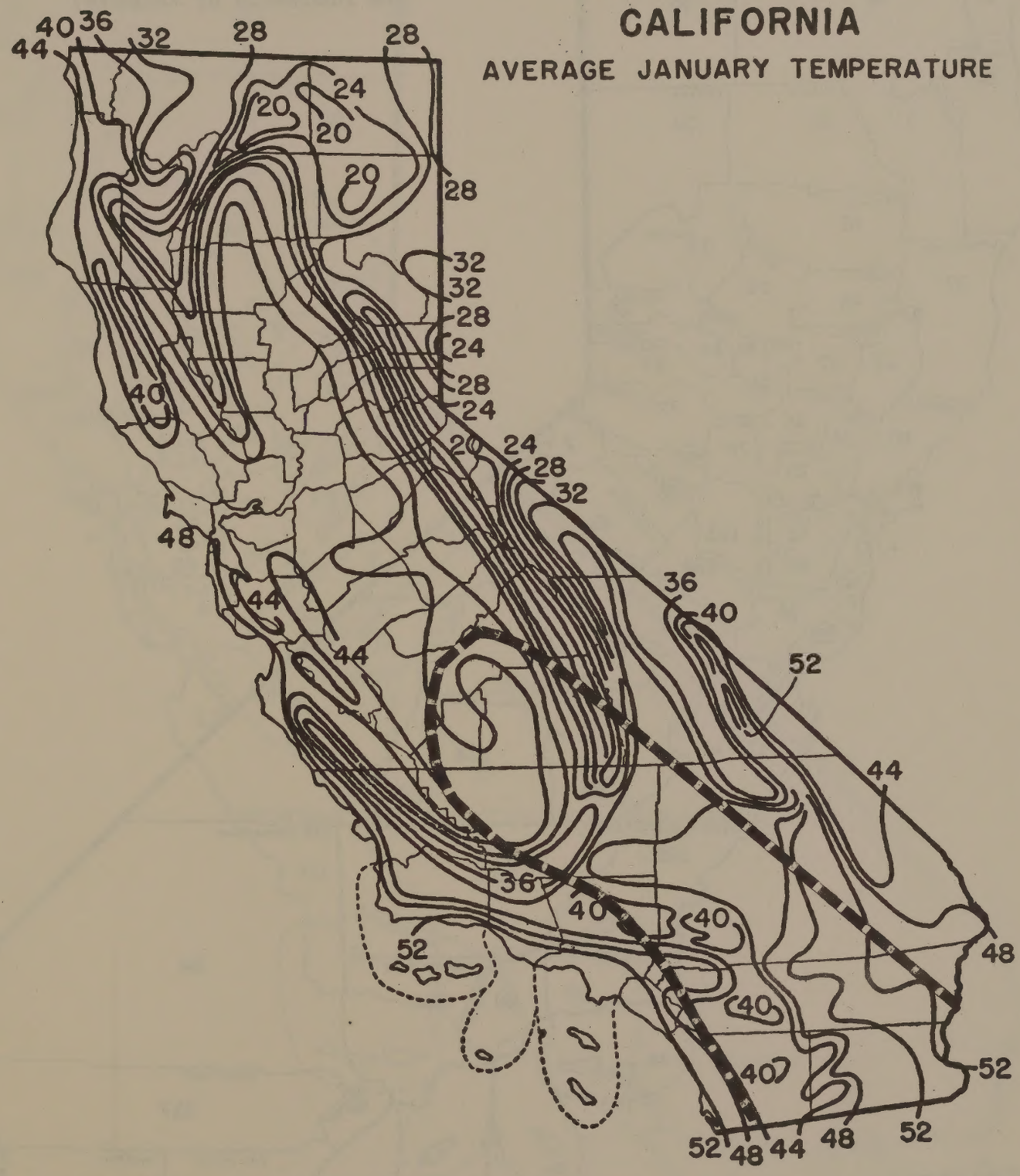

CALIFORNIA
AVERAGE JANUARY TEMPERATURE
Limits of Average Overwintering Area

FIGURE 17

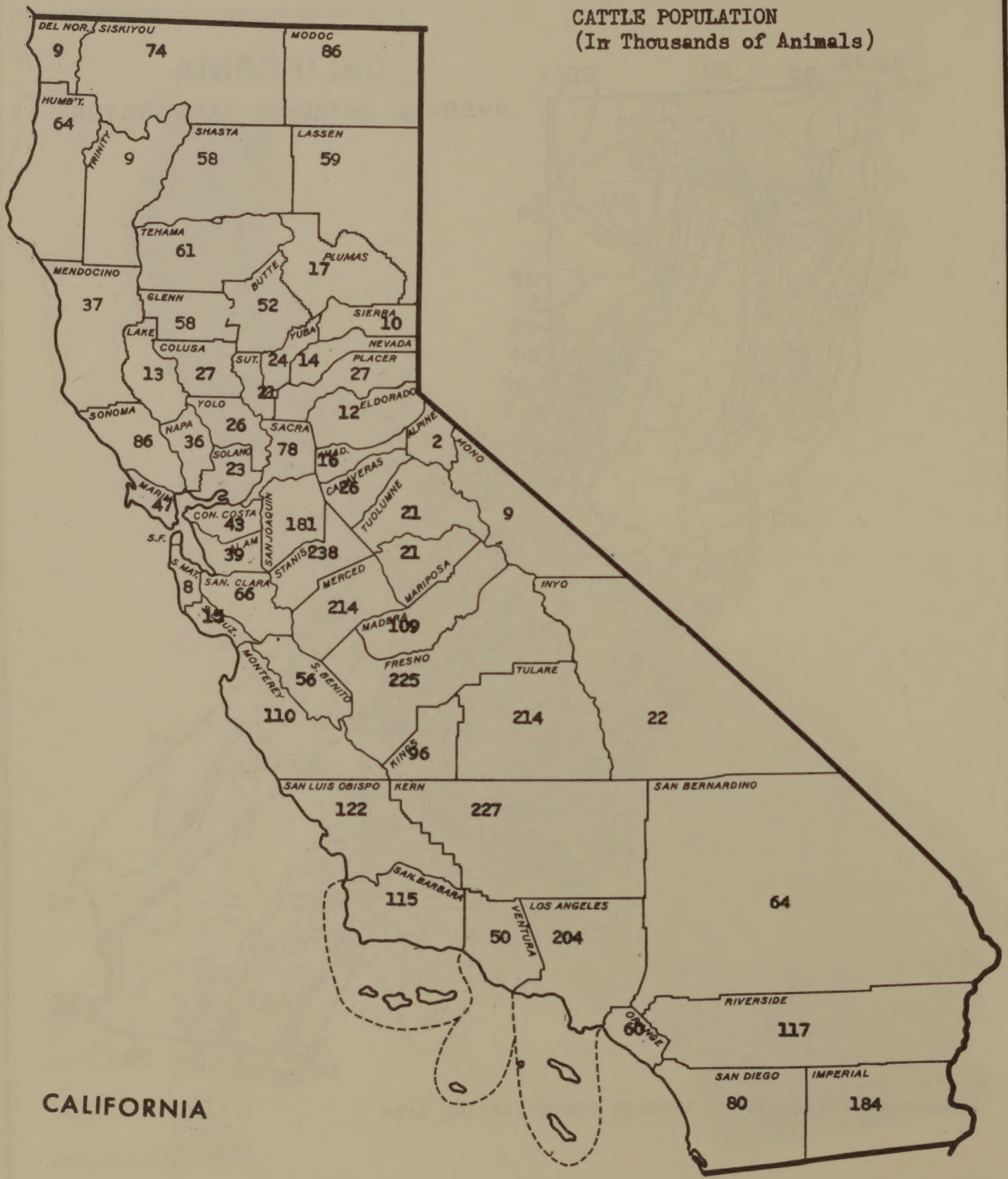

CATTLE POPULATION
(In Thousands of Animals)
DEL NOR. 9
SISKIYOU 74
MODOC 86
HUMB'T. 64
TRINITY 9
SHASTA 58
LASSEN 59
TEHAMA 61
PLUMAS 17
BUTTE 52
MENDOCINO 37
GLENN 58
SIERRA 10
LAKE
YUBA
NEVADA
COLUSA 13
SUT. 24
14
PLACER 27
27
ELDORADO 12
YOLO 26
SONOMA 86
NAPA 36
SACRA 78
ALPINE 2
MONO 9
SOLANO 23
AMAD. 16
CALAVERAS 26
MARIN 47
CON. COSTA 43
TUOLUMNE 21
SAN JOAQUIN 181
S.F.
ALAM 39
STANIS 238
21
S. MAT. 8
SAN. CLARA 66
MERCED 214
MARIPOSA
INYO
SANTA CRUZ
MADERA 109
MONTEREY 110
S. BENITO 56
FRESNO 225
TULARE 214
22
KINGS 96
SAN LUIS OBISPO 122
KERN 227
SAN BERNARDINO
SAN BARBARA 115
LOS ANGELES 50
VENTURA 204
64
ORANGE 60
RIVERSIDE 117
SAN DIEGO 80
IMPERIAL 184
CALIFORNIA
Total 3,982,000
Value $456,660,000

FIGURE 18

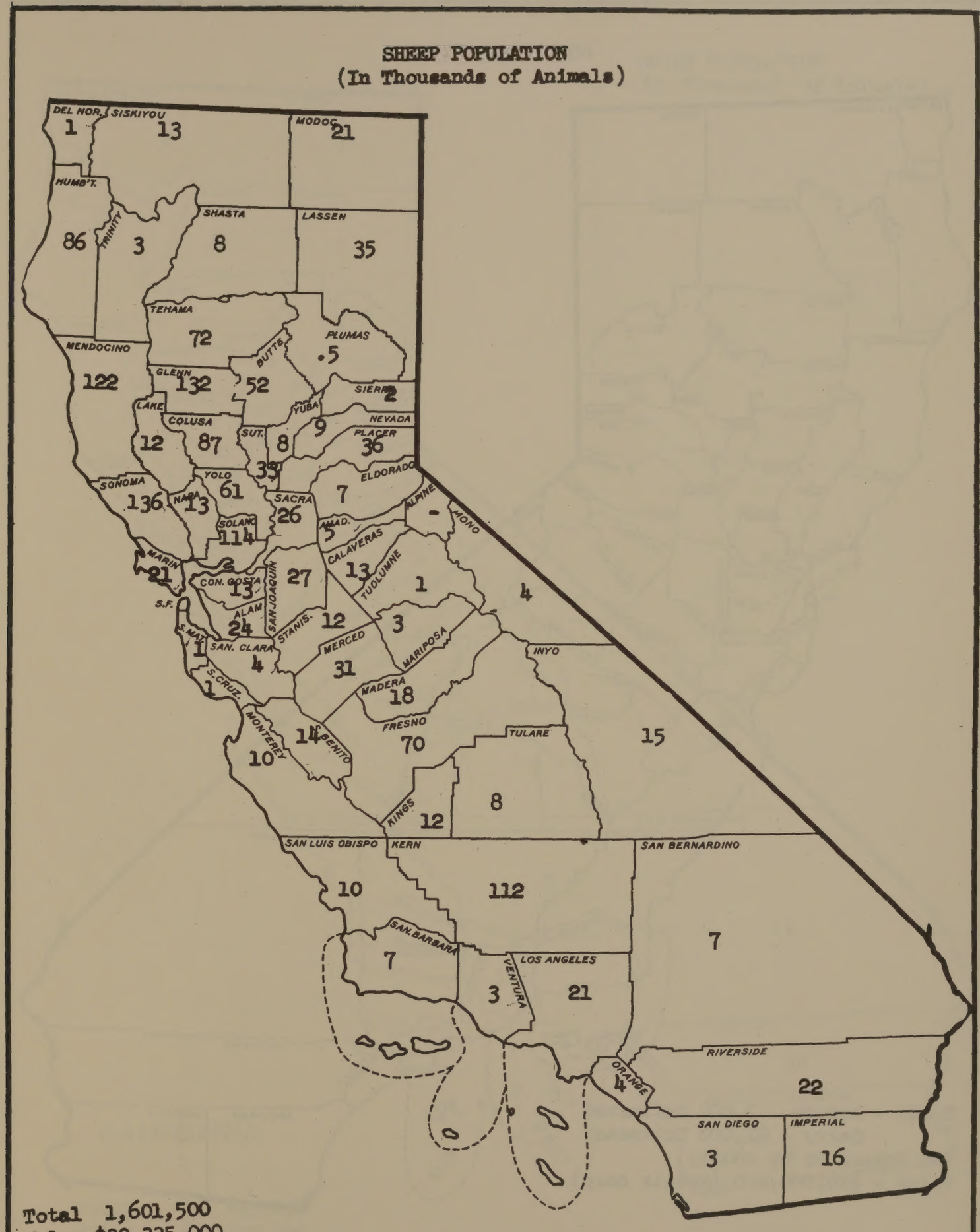
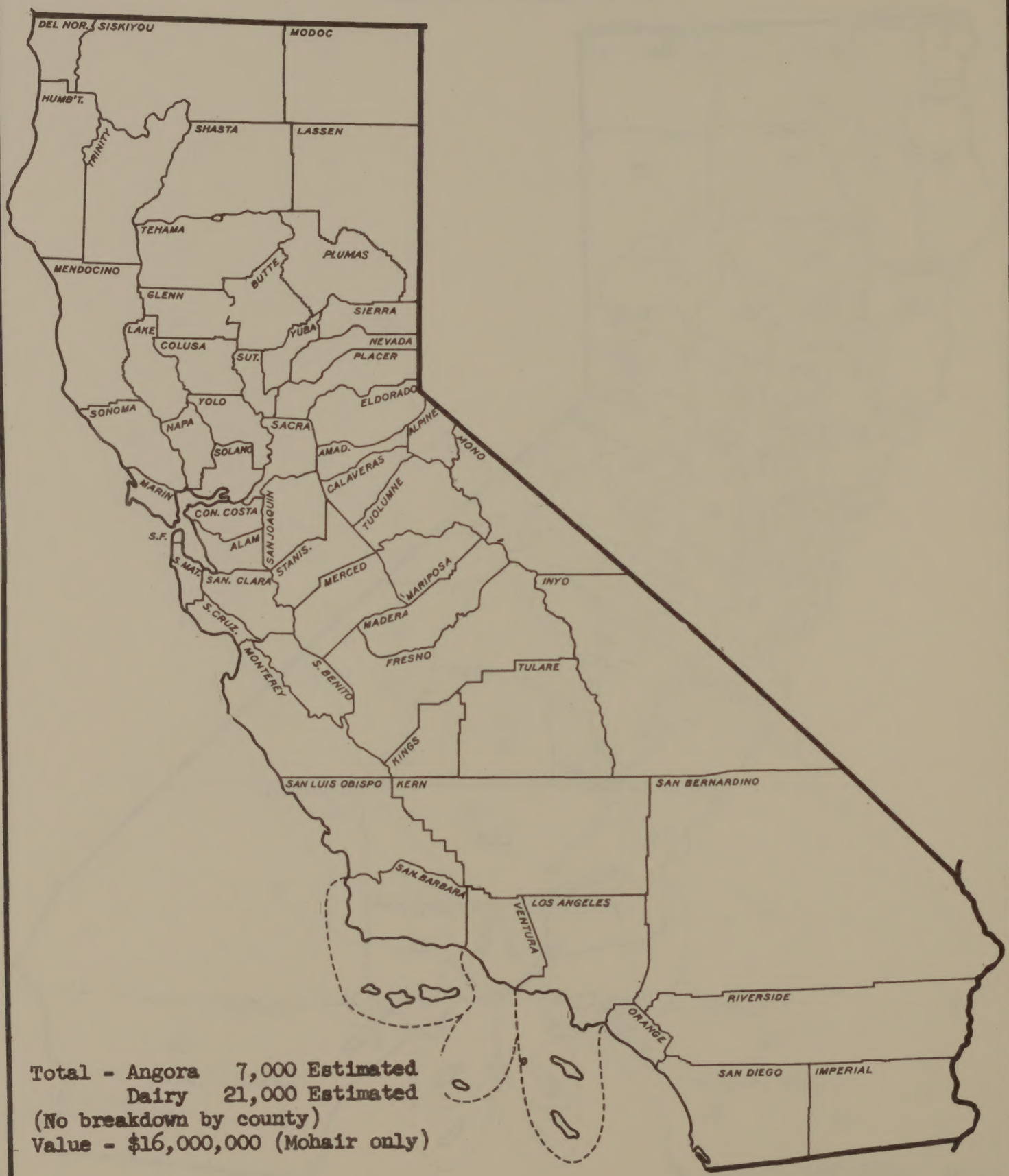

SHEEP POPULATION
(In Thousands of Animals)
DEL NOR. 1
SISKIYOU 13
MODOC 21
HUMB'T. 86
TRINITY 3
SHASTA 8
LASSEN 35
TEHAMA 72
PLUMAS .5
BUTTE 52
MENDOCINO 122
GLENN 132
SIERRA 2
LAKE 12
COLUSA 87
YUBA 9
NEVADA 36
SUT. 8
PLACER 33
ELDORADO 7
SONOMA 136
NAPA 13
YOLO 61
SACRA 26
ALPINE -
AMAD. 5
MONO 4
SOLANO 114
CALAVERAS 13
MARIN 21
CON. COSTA 13
SAN JOAQUIN 27
TUOLUMNE 1
S.F.
ALAM 24
STANIS. 12
MARIPOSA 3
S.MAT. 1
SAN. CLARA 4
MERCED 31
INYO 15
S.CRUZ 1
MADERA 18
MONTEREY 10
S.BENITO 14
FRESNO 70
TULARE 8
KINGS 12
SAN LUIS OBISPO 10
KERN 112
SAN BERNARDINO 7
SAN.BARBARA 7
LOS ANGELES 3
VENTURA 21
RIVERSIDE 22
ORANGE 4
SAN DIEGO 3
IMPERIAL 16
Total 1,601,500
Value $30,335,000
CALIFORNIA

FIGURE 19

GOAT POPULATION



Total - Angora 7,000 Estimated
Dairy 21,000 Estimated
(No breakdown by county)
Value - $16,000,000 (Mohair only)

CALIFORNIA

FIGURE 20

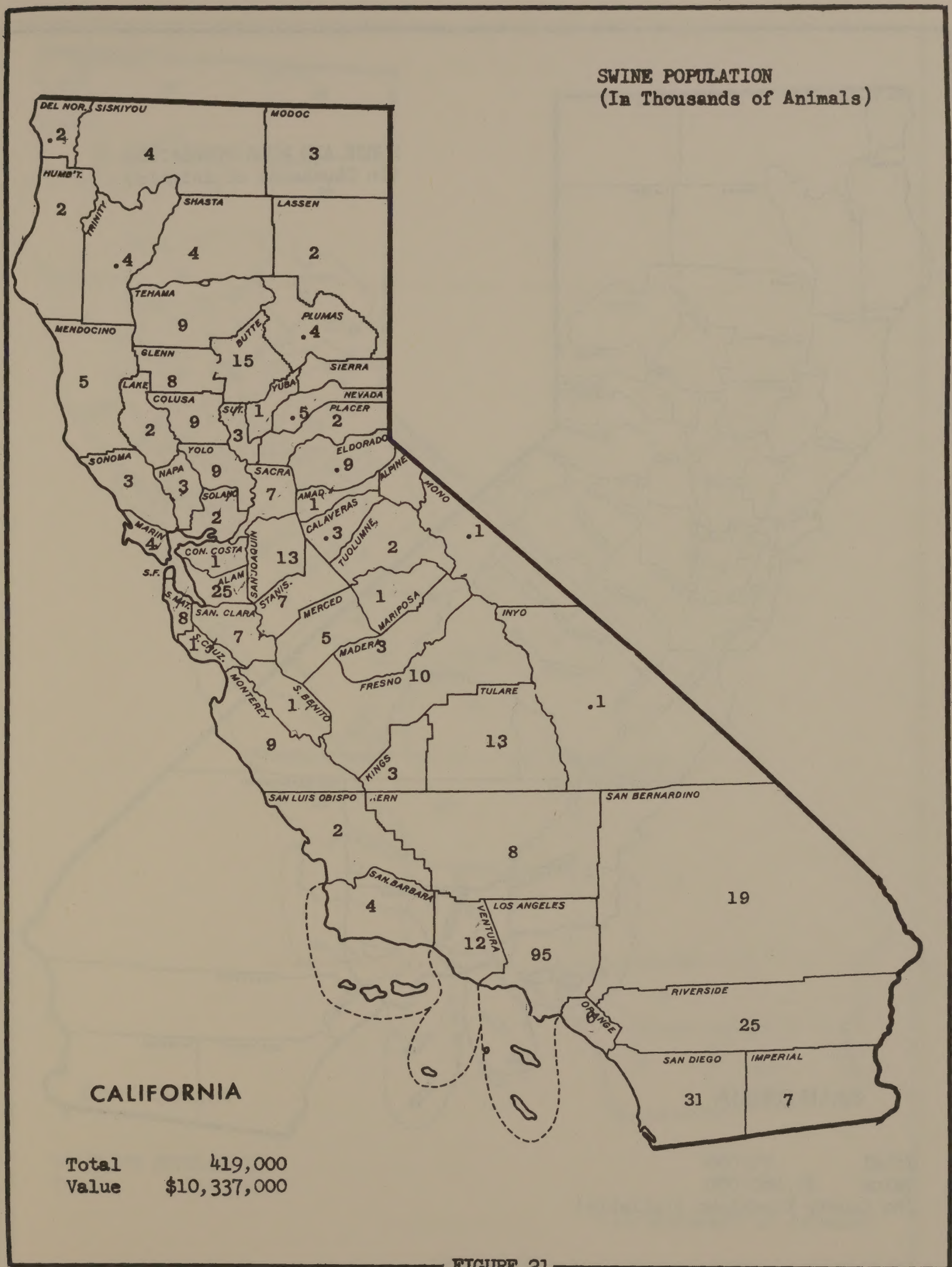

SWINE POPULATION
(In Thousands of Animals)
DEL NOR. .2
SISKIYOU 4
MODOC 3
HUMB'T. 2
TRINITY .4
SHASTA 4
LASSEN 2
TEHAMA 9
PLUMAS .4
MENDOCINO 5
BUTTE 15
GLENN 8
SIERRA
LAKE 2
YUBA
COLUSA 9
SUT. 1
NEVADA .5
PLACER 2
SONOMA 3
YOLO 9
NAPA 3
SACRA 7
ELDORADO .9
ALPINE
SOLANO 2
AMAD. 1
MONO .1
MARIN 4
CALAVERAS .3
CON. COSTA 1
TUOLUMNE 2
S.F.
ALAM 25
SAN JOAQUIN 13
STANIS. 7
S. MAT. 8
SAN. CLARA 7
MERCED 5
MARIPOSA 1
INYO .1
S. CRUZ 1
MADERA 3
FRESNO 10
MONTEREY 9
S. BENITO 1
TULARE 13
KINGS 3
SAN LUIS OBISPO 2
SAN BERNARDINO 19
SAN BARBARA 4
LOS ANGELES 95
VENTURA 12
RIVERSIDE 25
ORANGE 8
SAN DIEGO 31
IMPERIAL 7
CALIFORNIA
Total 419,000
Value $10,337,000

FIGURE 21

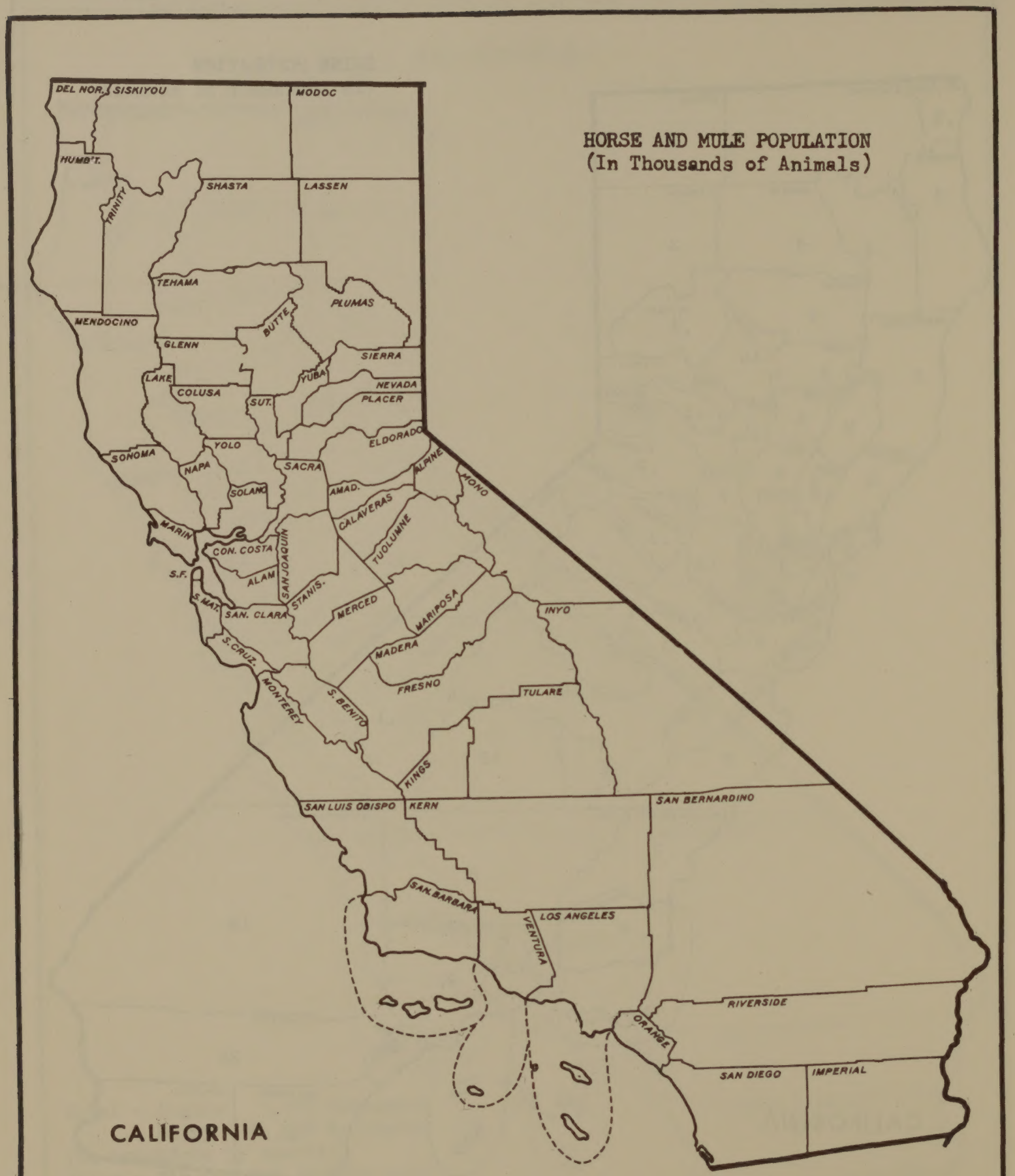
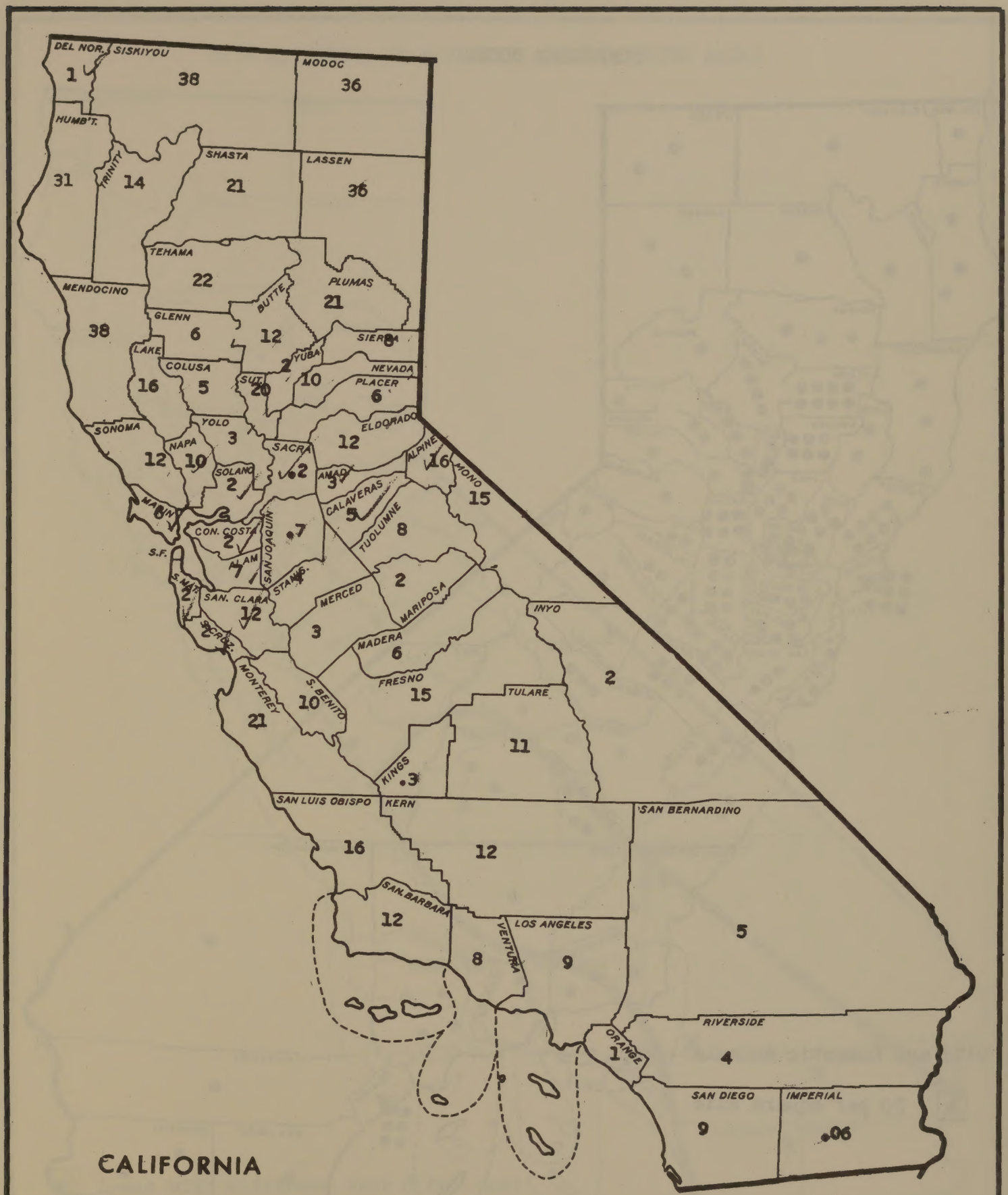

HORSE AND MULE POPULATION
(In Thousands of Animals)
DEL NOR.
SISKIYOU
MODOC
HUMB'T.
TRINITY
SHASTA
LASSEN
TEHAMA
PLUMAS
MENDOCINO
BUTTE
GLENN
SIERRA
LAKE
YUBA
NEVADA
COLUSA
SUT.
PLACER
ELDORADO
SONOMA
YOLO
ALPINE
MONO
NAPA
SACRA
AMAD.
SOLANO
CALAVERAS
MARIN
TUOLUMNE
CON. COSTA
SAN JOAQUIN
S.F.
ALAM
STANIS.
S. MAT.
SAN. CLARA
MERCED
MARIPOSA
INYO
S. CRUZ.
MADERA
MONTEREY
FRESNO
S. BENITO
TULARE
KINGS
SAN LUIS OBISPO
KERN
SAN BERNARDINO
SAN BARBARA
LOS ANGELES
VENTURA
RIVERSIDE
ORANGE
SAN DIEGO
IMPERIAL
CALIFORNIA
Total 70,000
Value $7,560,000
(No County Breakdown Available)

FIGURE 22



CALIFORNIA

WILDLIFE POPULATION
Total 611,260

(In Thousands of Animals)

FIGURE 23

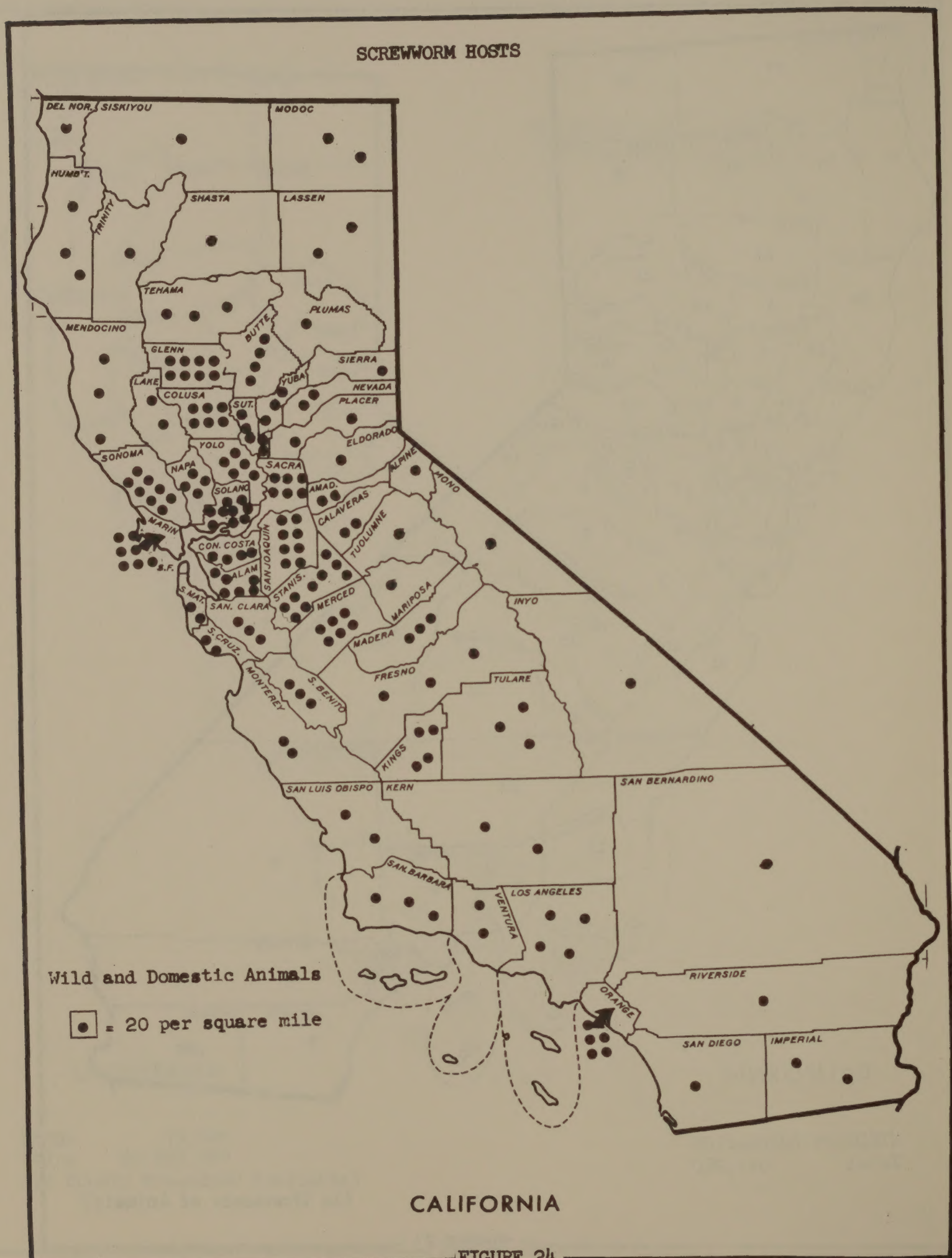
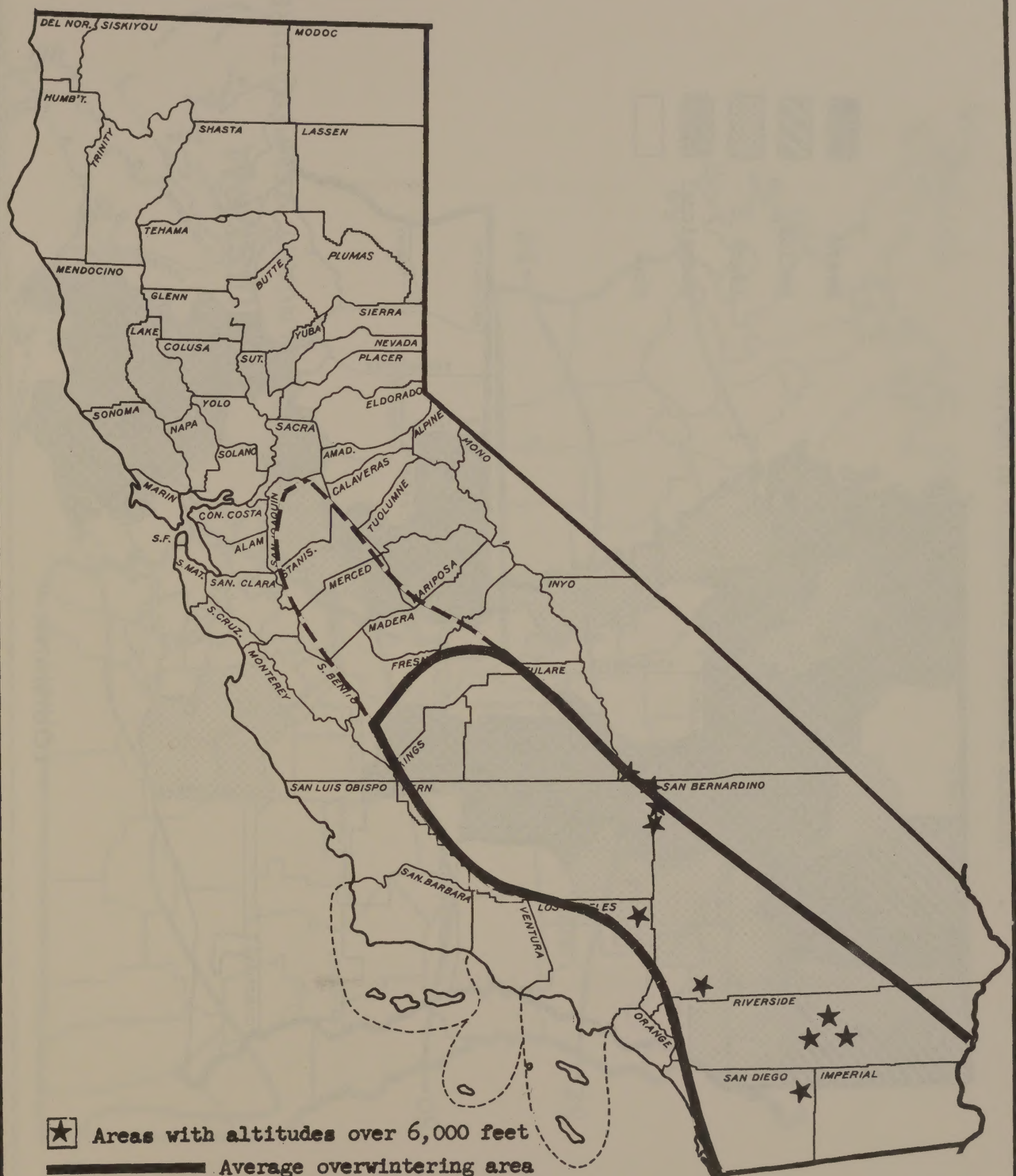

SCREWWORM HOSTS
DEL NOR.
SISKIYOU
MODOC
HUMB'T.
TRINITY
SHASTA
LASSEN
TEHAMA
PLUMAS
MENDOCINO
BUTTE
GLENN
SIERRA
LAKE
YUBA
NEVADA
COLUSA
SUT.
PLACER
YOLO
ELDORADO
SONOMA
NAPA
SACRA
ALPINE
MONO
SOLANO
AMAD.
CALAVERAS
MARIN
TUOLUMNE
CON. COSTA
S.F.
SAN JOAQUIN
ALAM
STANIS.
S. MAT.
SAN. CLARA
MERCED
MARIPOSA
INYO
S. CRUZ.
MADERA
FRESNO
MONTEREY
S. BENITO
TULARE
KINGS
SAN LUIS OBISPO
KERN
SAN BERNARDINO
SAN. BARBARA
LOS ANGELES
VENTURA
RIVERSIDE
ORANGE
SAN DIEGO
IMPERIAL
Wild and Domestic Animals
= 20 per square mile
CALIFORNIA

FIGURE 24

HIGH ALTITUDES IN SCREWWORM OVERWINTERING AREAS



CALIFORNIA

FIGURE 25

AVERAGE SCREWWORM INFESTATION BY PARISH

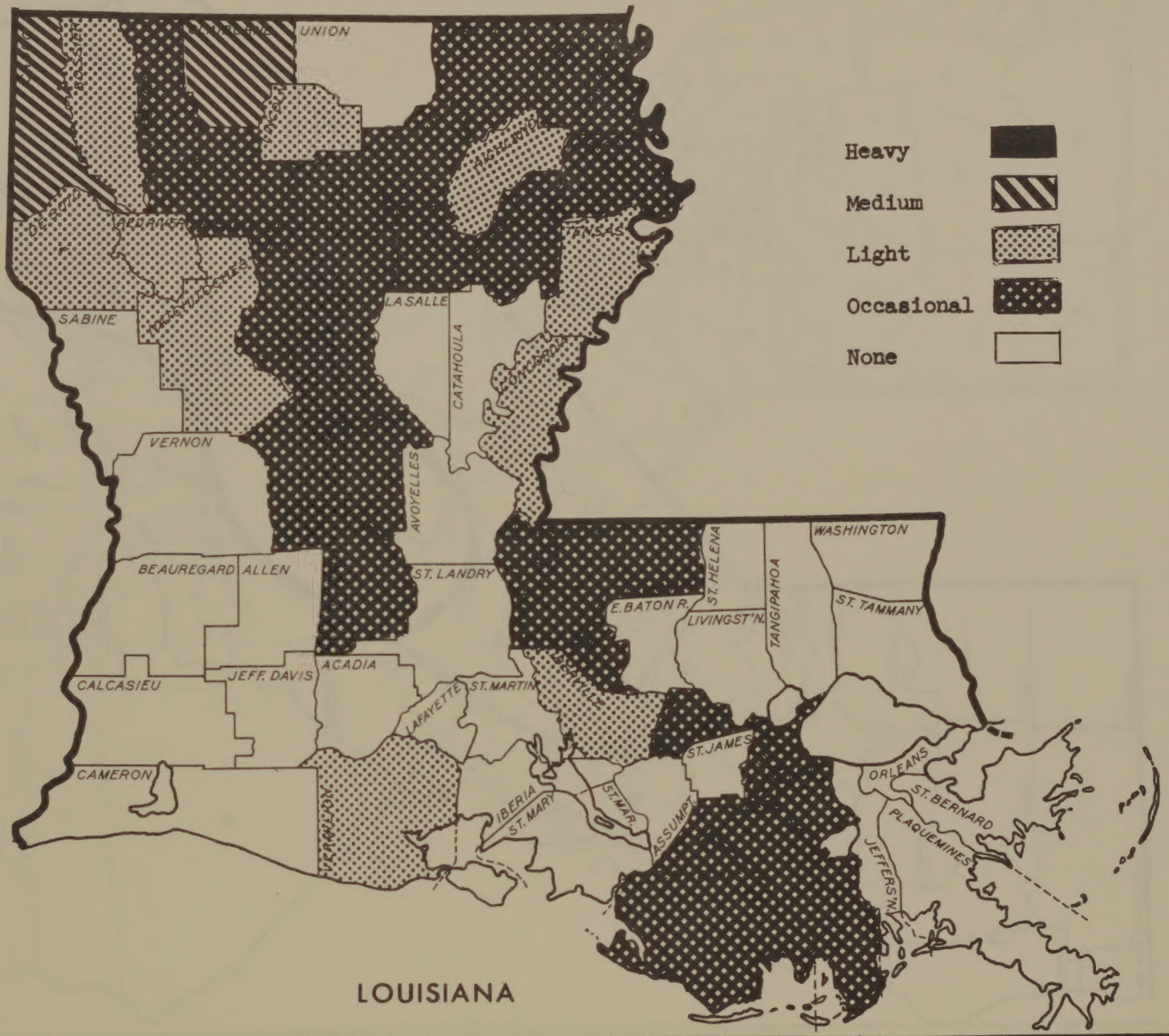


FIGURE 26

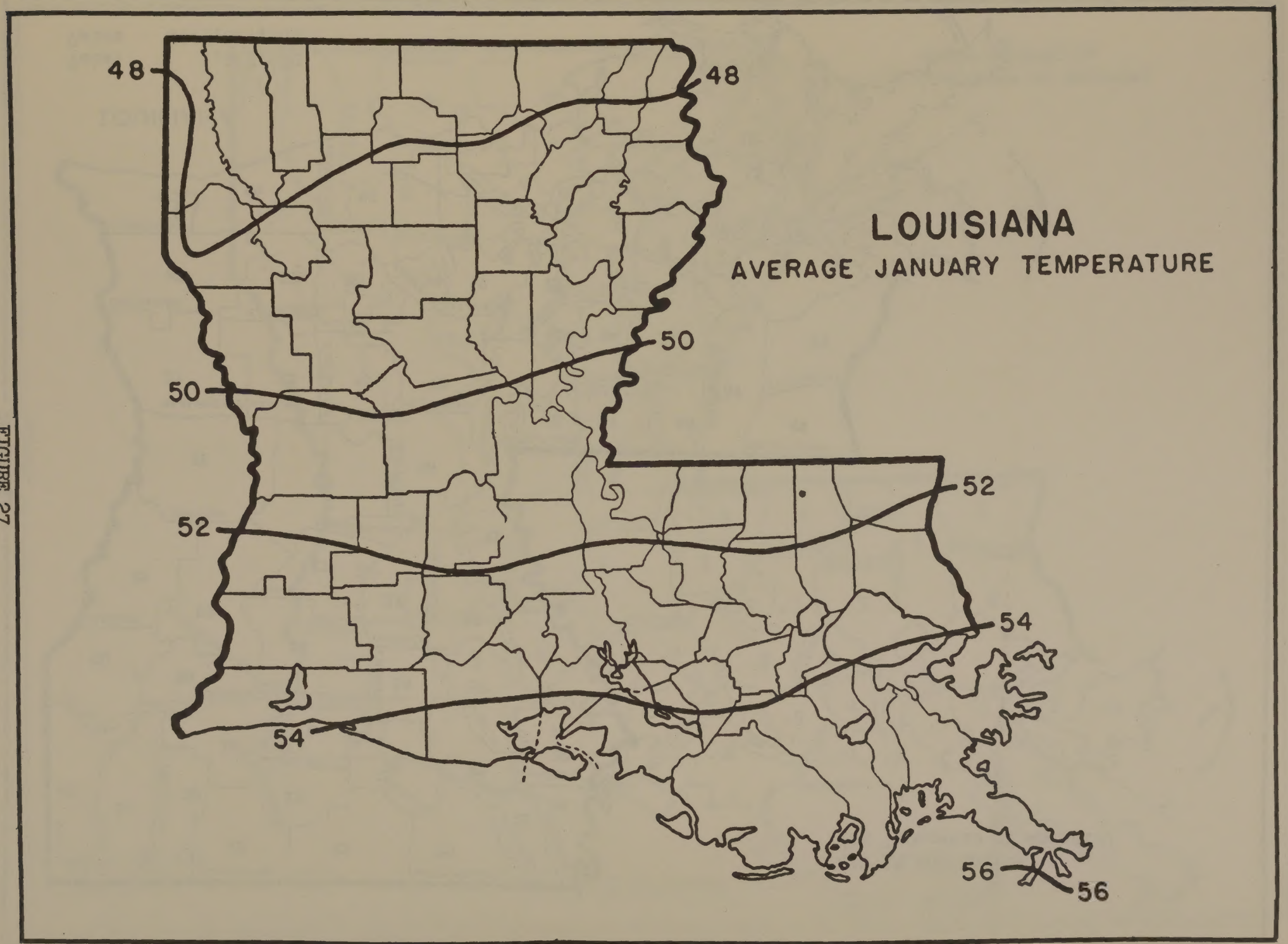

LOUISIANA
AVERAGE JANUARY TEMPERATURE
48
48
50
50
52
52
54
54
56
56

FIGURE 27

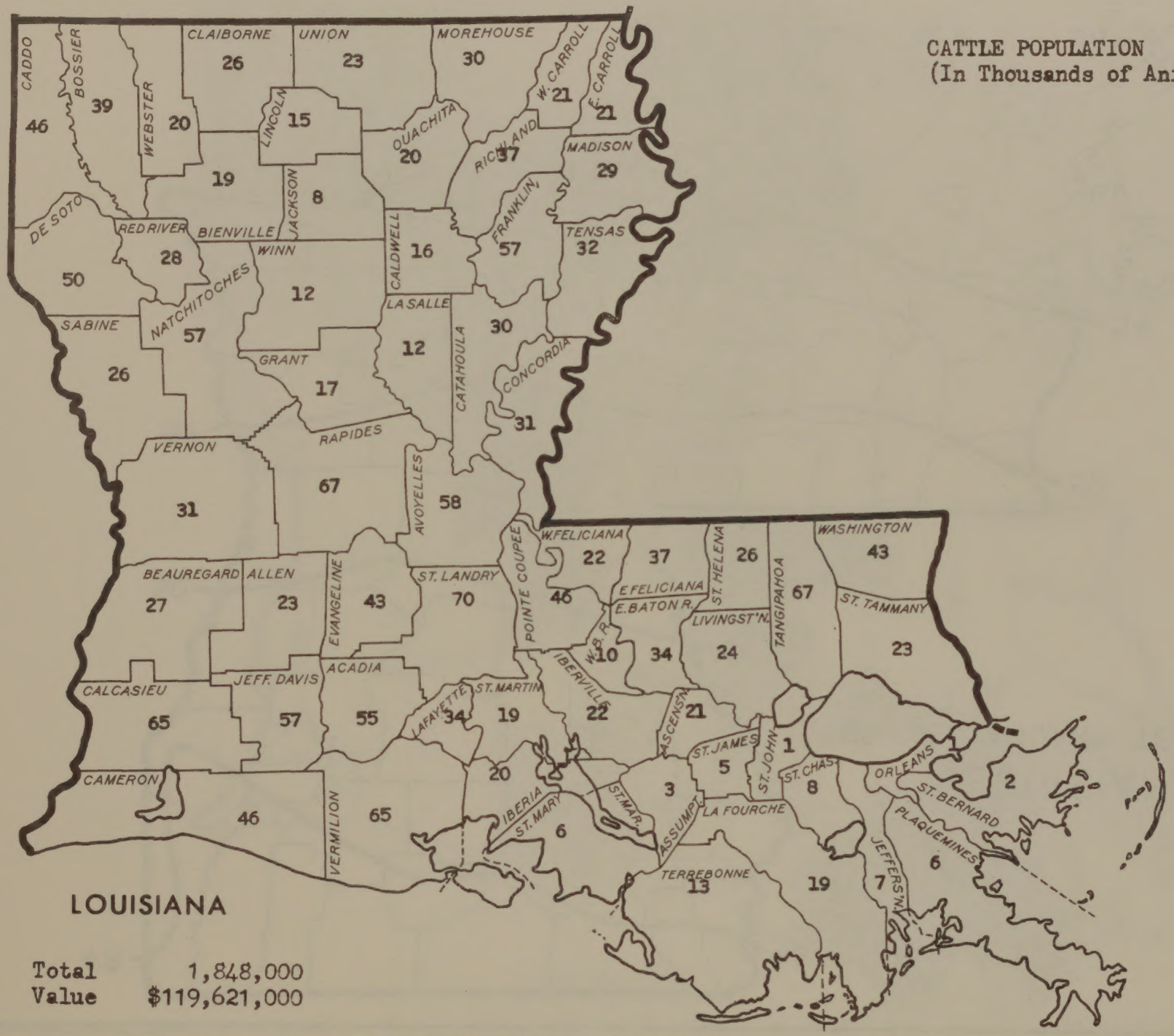

CATTLE POPULATION
(In Thousands of Animals)
CADDO 46
BOSSIER 39
WEBSTER 20
CLAIBORNE 26
UNION 23
MOREHOUSE 30
W. CARROLL 21
E. CARROLL 21
LINCOLN 15
OUACHITA 20
RICHLAND 37
MADISON 29
JACKSON 8
DE SOTO 50
RED RIVER 28
BIENVILLE 19
WINN 12
CALDWELL 16
FRANKLIN 57
TENSAS 32
NATCHITOCHES 57
LA SALLE 12
CATAHOULA 30
CONCORDIA 31
SABINE 26
GRANT 17
VERNON 31
RAPIDES 67
AVOYELLES 58
POINTE COUPEE 22
W. FELICIANA 37
E. FELICIANA 46
ST. HELENA 26
WASHINGTON 43
TANGIPAHOA 67
ST. TAMMANY 23
LIVINGST'N 24
E. BATON R. 34
W. B. R. 10
BEAUREGARD 27
ALLEN 23
EVANGELINE 43
ST. LANDRY 70
ACADIA 55
JEFF. DAVIS 57
CALCASIEU 65
IBERVILLE 22
ASCENSN 21
ST. JAMES 5
ST. JOHN 1
ST. CHAS 8
ORLEANS 2
ST. BERNARD 6
PLAQUEMINES 6
JEFFERS'N 7
LAFAYETTE 34
ST. MARTIN 19
ST. MARY 6
IBERIA 20
ST. MAR. 3
ASSUMPT'N
LA FOURCHE 19
TERREBONNE 13
VERMILION 65
CAMERON 46
LOUISIANA
Total 1,848,000
Value $119,621,000

FIGURE 28

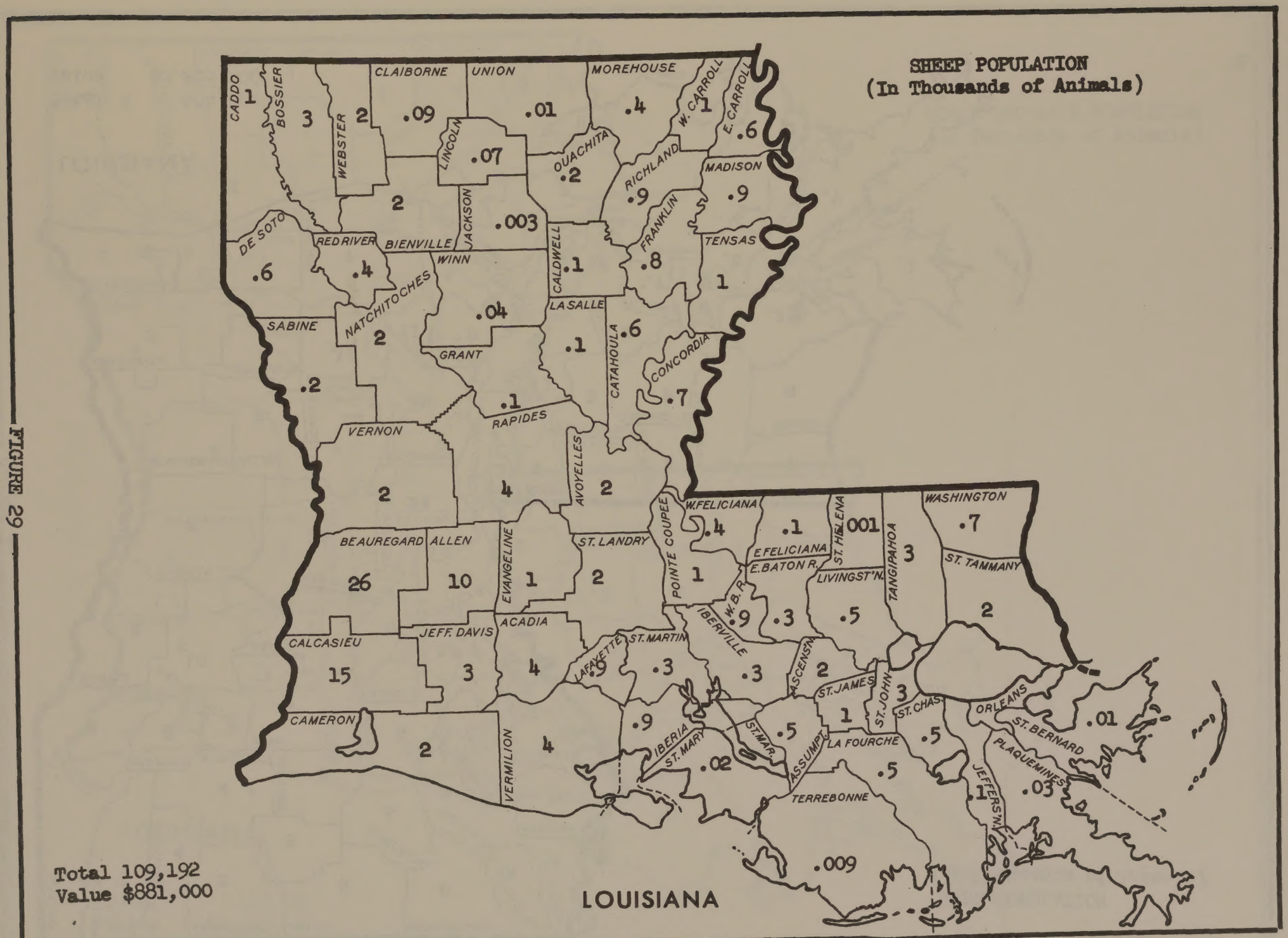

SHEEP POPULATION
(In Thousands of Animals)
CADDO 1
BOSSIER 3
WEBSTER 2
CLAIBORNE .09
UNION .01
MOREHOUSE .4
W. CARROLL 1
E. CARROLL .6
LINCOLN .07
OUACHITA .2
RICHLAND .9
MADISON .9
2
JACKSON .003
DE SOTO .6
REDRIVER .4
BIENVILLE
WINN .04
CALDWELL .1
FRANKLIN .8
TENSAS 1
LASALLE .1
CATAHOULA .6
CONCORDIA .7
SABINE .2
NATCHITOCHES 2
GRANT .1
RAPIDES .1
VERNON 2 4
AVOYELLES 2
BEAUREGARD 26
ALLEN 10
EVANGELINE 1
ST. LANDRY 2
POINTE COUPEE 1
W.FELICIANA .4
E FELICIANA .1
E.BATON R.
ST. HELENA .001
LIVINGST'N .5
TANGIPAHOA 3
WASHINGTON .7
ST. TAMMANY 2
W.B.R. .9 .3
IBERVILLE .3
CALCASIEU 15
JEFF. DAVIS 3
ACADIA 4
LAFAYETTE .9
ST. MARTIN .3
ASCENSN 2
ST. JAMES 1
ST. JOHN 3
ST. CHAS .5
ORLEANS .01
ST. BERNARD
PLAQUEMINES .03
JEFFERSN .1
CAMERON 2
VERMILION 4
IBERIA .9
ST. MARY .02
ST.MAR. .5
ASSUMPT.
LA FOURCHE .5
TERREBONNE
.009
Total 109,192
Value $881,000
LOUISIANA

FIGURE 29

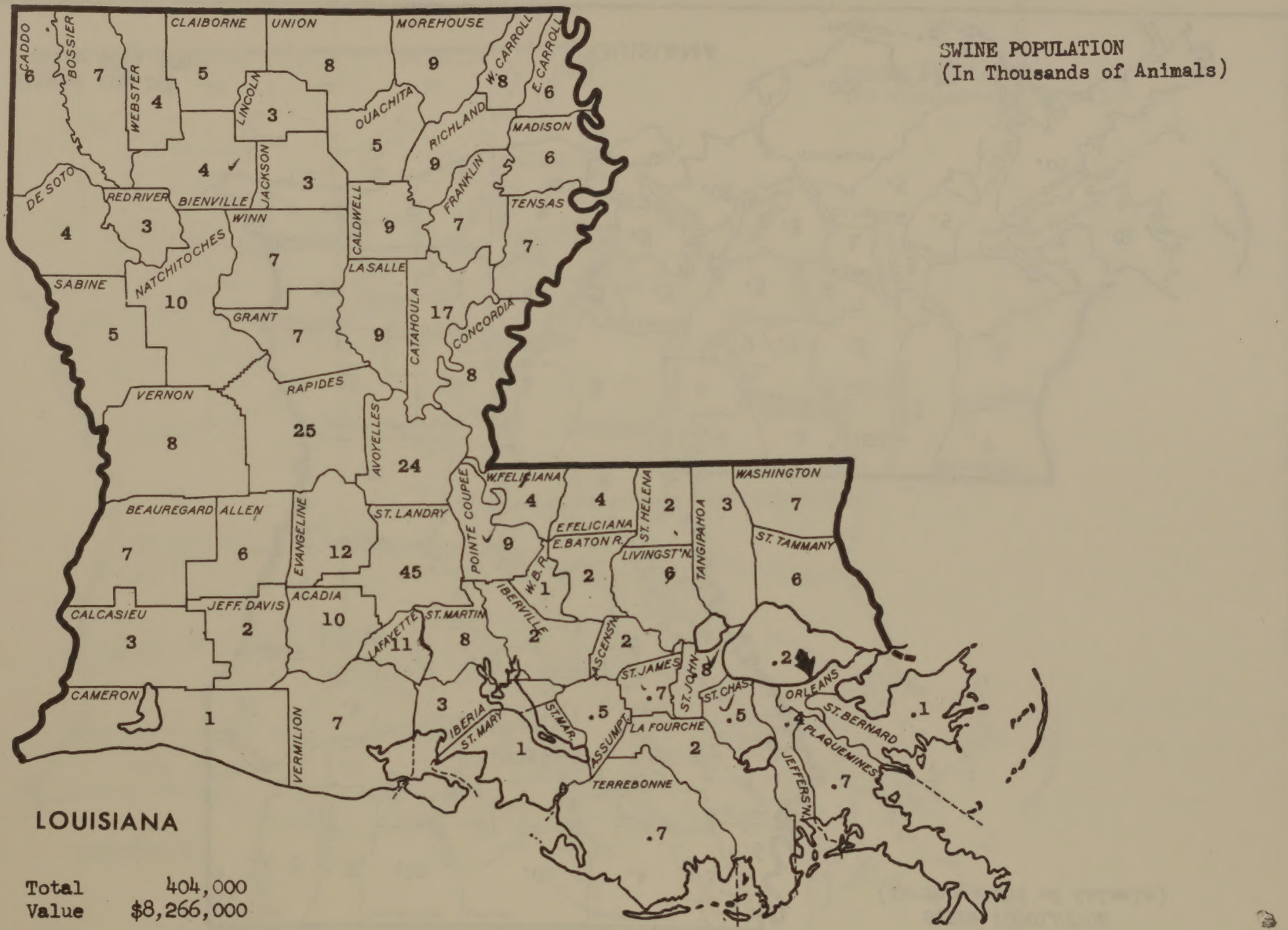

SWINE POPULATION
(In Thousands of Animals)
CADDO
BOSSIER
WEBSTER
CLAIBORNE
UNION
MOREHOUSE
W. CARROLL
E. CARROLL
LINCOLN
OUACHITA
RICHLAND
MADISON
JACKSON
FRANKLIN
TENSAS
DE SOTO
RED RIVER
BIENVILLE
WINN
CALDWELL
LA SALLE
CATAHOULA
CONCORDIA
NATCHITOCHES
SABINE
GRANT
VERNON
RAPIDES
AVOYELLES
POINTE COUPEE
W. FELICIANA
E. FELICIANA
E. BATON R.
W. B. R.
ST. HELENA
LIVINGST'N.
TANGIPAHOA
WASHINGTON
ST. TAMMANY
BEAUREGARD
ALLEN
EVANGELINE
ST. LANDRY
IBERVILLE
ASCENSN
ST. JAMES
ST. JOHN
ST. CHAS
ORLEANS
ST. BERNARD
PLAQUEMINES
JEFFERS'N
JEFF. DAVIS
ACADIA
CALCASIEU
LAFAYETTE
ST. MARTIN
IBERIA
ST. MARY
ST. MAR.
ASSUMPT.
LA FOURCHE
TERREBONNE
CAMERON
VERMILION
LOUISIANA
Total 404,000
Value $8,266,000

FIGURE 30

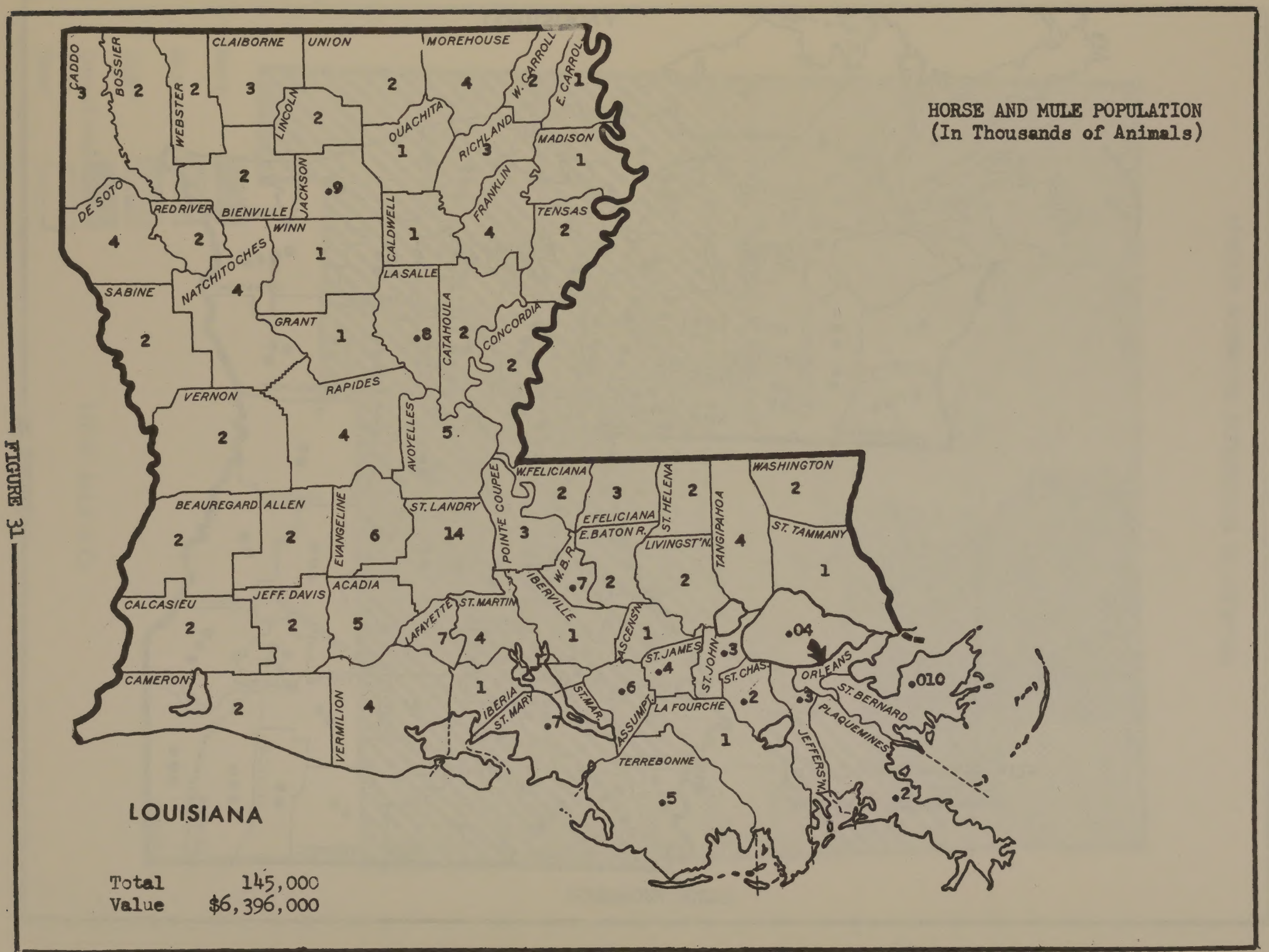

HORSE AND MULE POPULATION
(In Thousands of Animals)
CADDO 3
BOSSIER 2
WEBSTER 2
CLAIBORNE 3
UNION 2
MOREHOUSE 4
W. CARROLL 2
E. CARROLL 1
LINCOLN 2
OUACHITA 1
RICHLAND 3
MADISON 1
JACKSON .9
FRANKLIN 4
TENSAS 2
DE SOTO 4
RED RIVER 2
BIENVILLE 2
WINN 1
CALDWELL 1
LA SALLE .8
CATAHOULA 2
CONCORDIA 2
SABINE 2
NATCHITOCHES 4
GRANT 1
VERNON 2
RAPIDES 4
AVOYELLES 5
BEAUREGARD 2
ALLEN 2
EVANGELINE 6
ST. LANDRY 14
POINTE COUPEE 3
W.FELICIANA 2
E.FELICIANA 3
E.BATON R. .7
W.B.R. 2
IBERVILLE 1
ST. HELENA 2
LIVINGST'N 2
TANGIPAHOA 4
WASHINGTON 2
ST. TAMMANY 1
JEFF. DAVIS 2
ACADIA 5
CALCASIEU 2
LAFAYETTE 7
ST. MARTIN 4
ASCENSN 1
ST. JAMES .4
ST. JOHN .3
ST. CHAS .2
ORLEANS .04
.010
ST. BERNARD .3
PLAQUEMINES .2
JEFFERSN
CAMERON 2
VERMILION 4
IBERIA 1
ST. MARY .7
ST. MAR. .6
ASSUMPT. 1
LA FOURCHE .2
TERREBONNE .5
LOUISIANA
Total 145,000
Value $6,396,000

FIGURE 31

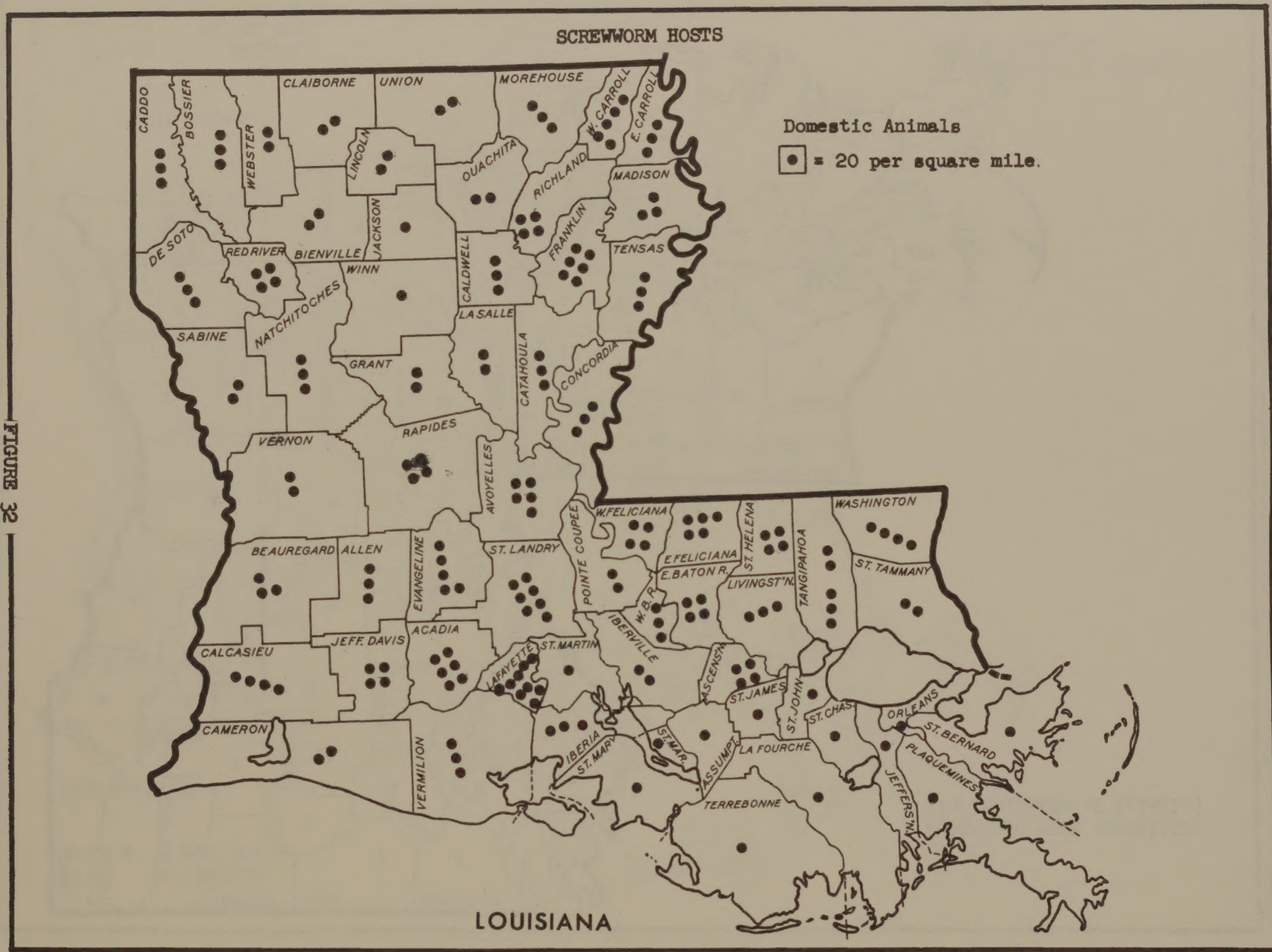
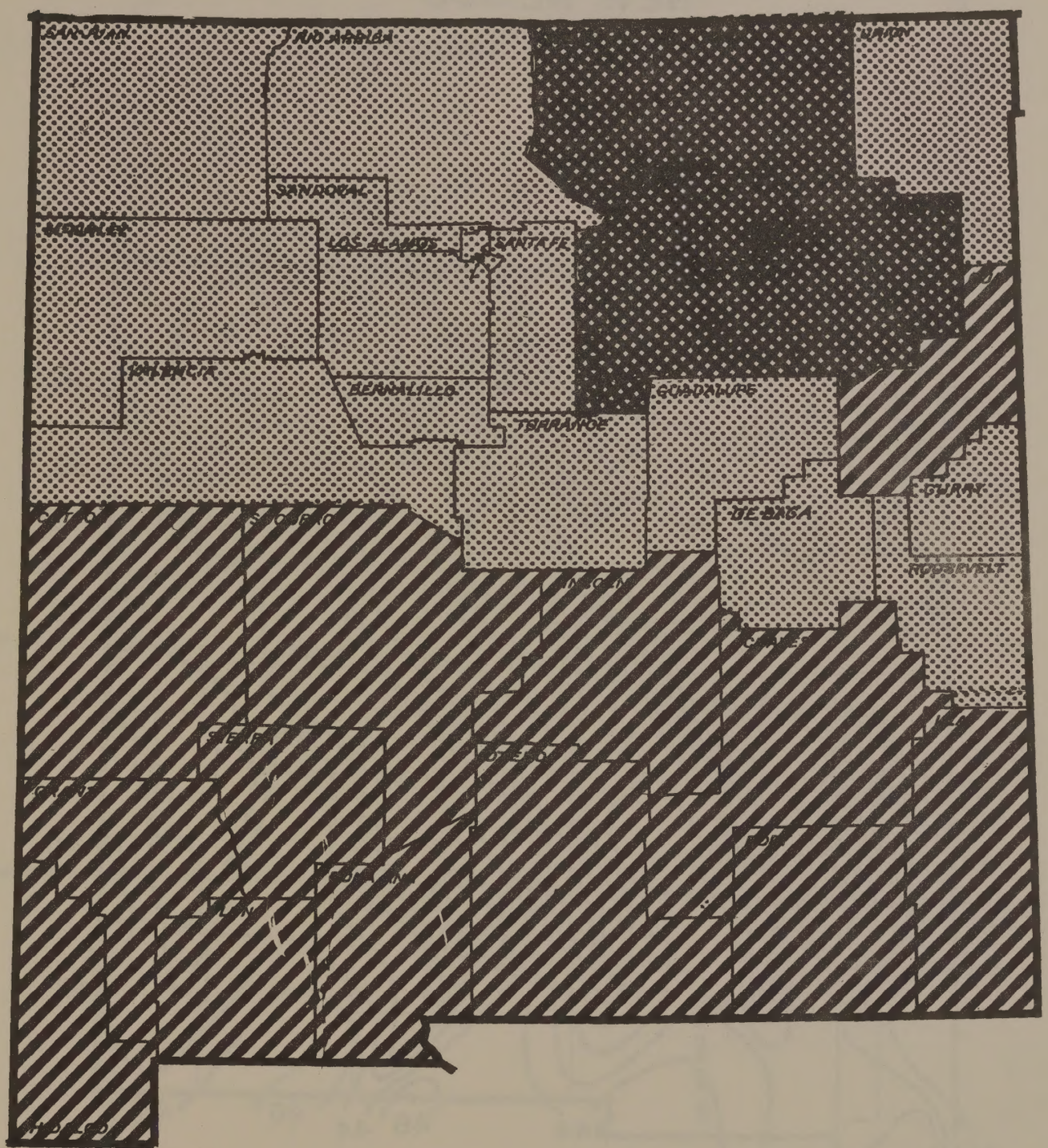

SCREWWORM HOSTS
Domestic Animals
= 20 per square mile.
CADDO
BOSSIER
WEBSTER
CLAIBORNE
UNION
MOREHOUSE
W. CARROLL
E. CARROLL
LINCOLN
OUACHITA
RICHLAND
MADISON
DE SOTO
RED RIVER
BIENVILLE
JACKSON
FRANKLIN
TENSAS
WINN
CALDWELL
LA SALLE
SABINE
NATCHITOCHES
CATAHOULA
CONCORDIA
GRANT
RAPIDES
VERNON
AVOYELLES
POINTE COUPEE
W. FELICIANA
E. FELICIANA
E. BATON R.
W. B. R.
ST. HELENA
LIVINGST'N.
TANGIPAHOA
WASHINGTON
ST. TAMMANY
BEAUREGARD
ALLEN
EVANGELINE
ST. LANDRY
IBERVILLE
ACADIA
JEFF. DAVIS
CALCASIEU
LAFAYETTE
ST. MARTIN
ASCENSN.
ST. JAMES
ST. JOHN
ST. CHAS.
ORLEANS
ST. BERNARD
PLAQUEMINES
JEFFERS'N.
CAMERON
VERMILION
IBERIA
ST. MARY
ST. MAR.
ASSUMPT.
LA FOURCHE
TERREBONNE
LOUISIANA

FIGURE 32

AVERAGE SCREWWORM INFESTATION BY COUNTIES



Heavy

Medium

Light

Occasional

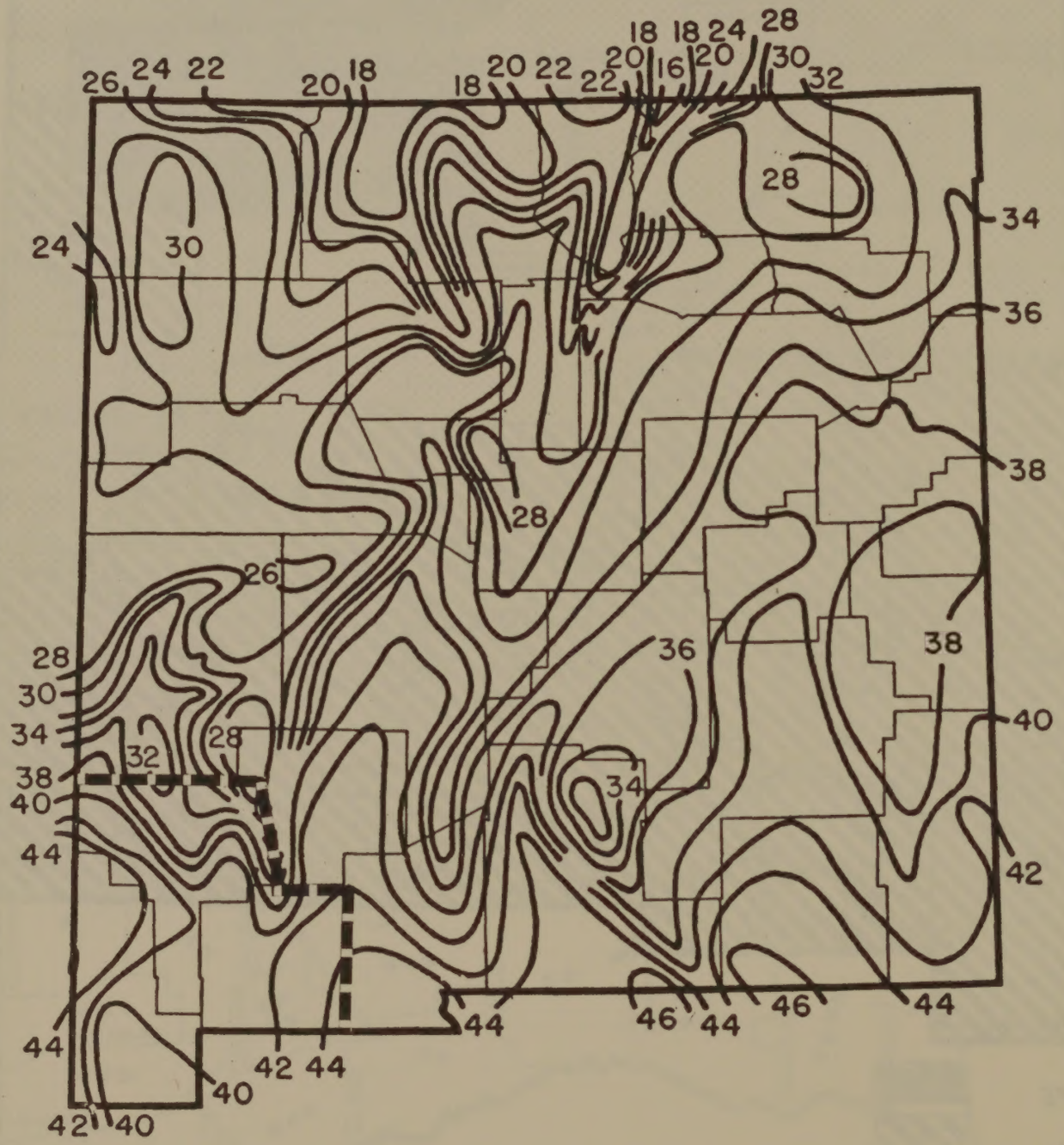
None

NEW MEXICO

FIGURE 33

NEW MEXICO

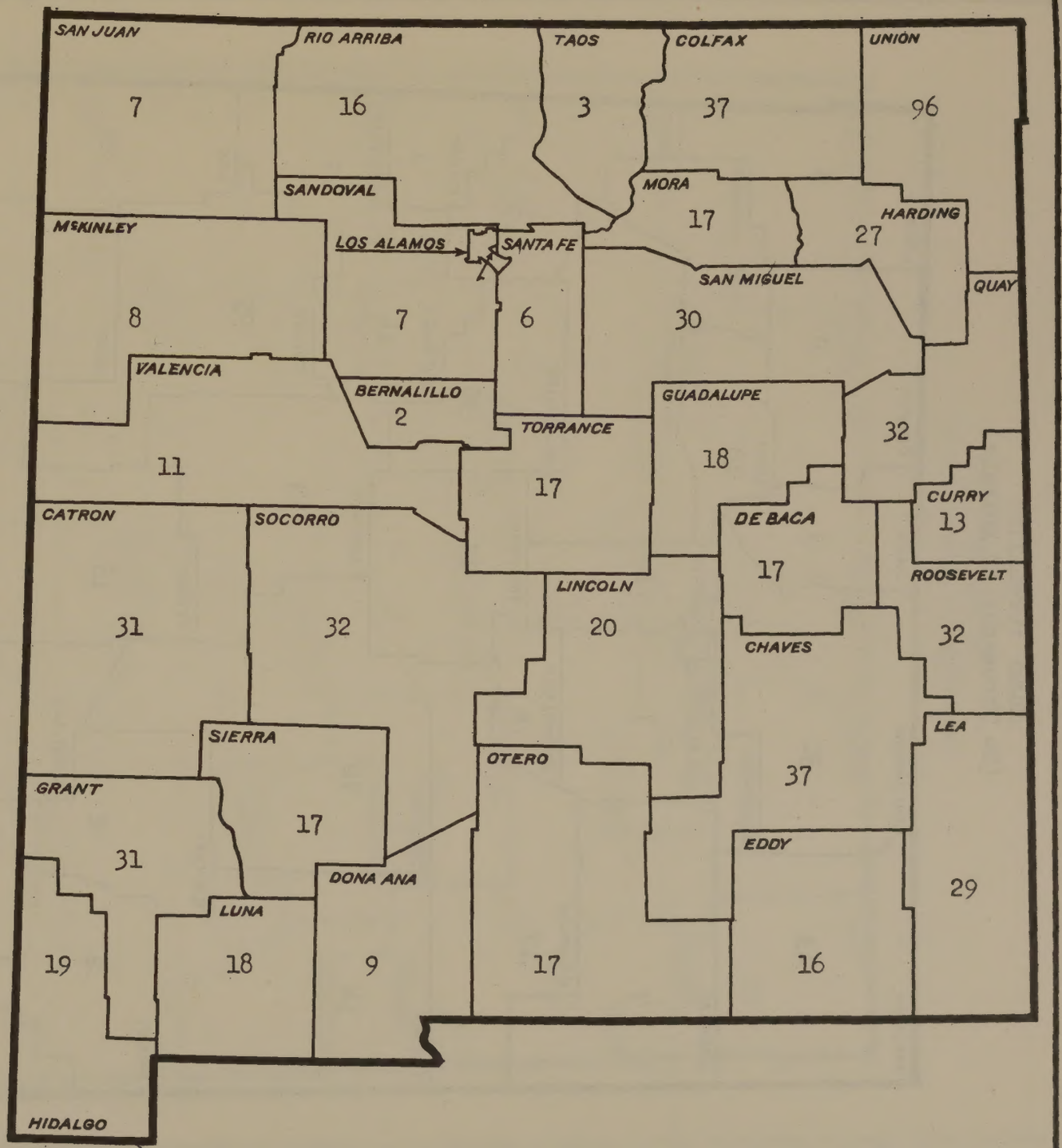
AVERAGE JANUARY TEMPERATURE



Occasional Overwintering Area

FIGURE 34

CATTLE POPULATION
(In Thousands of Animals)

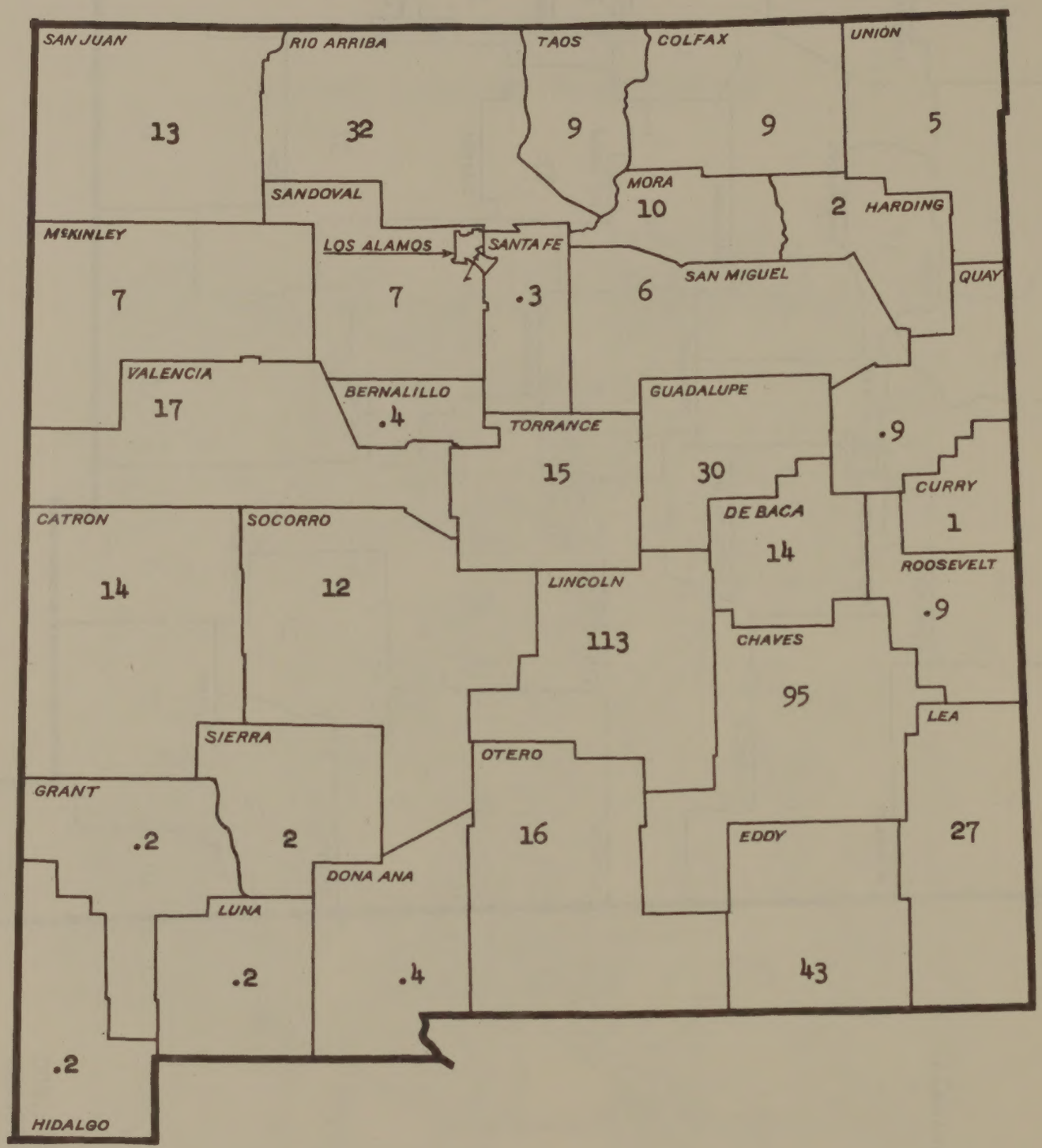


NEW MEXICO

Total	672,000
Value	$81,972,000

FIGURE 35

SHEEP POPULATION
(In Thousands of Animals)



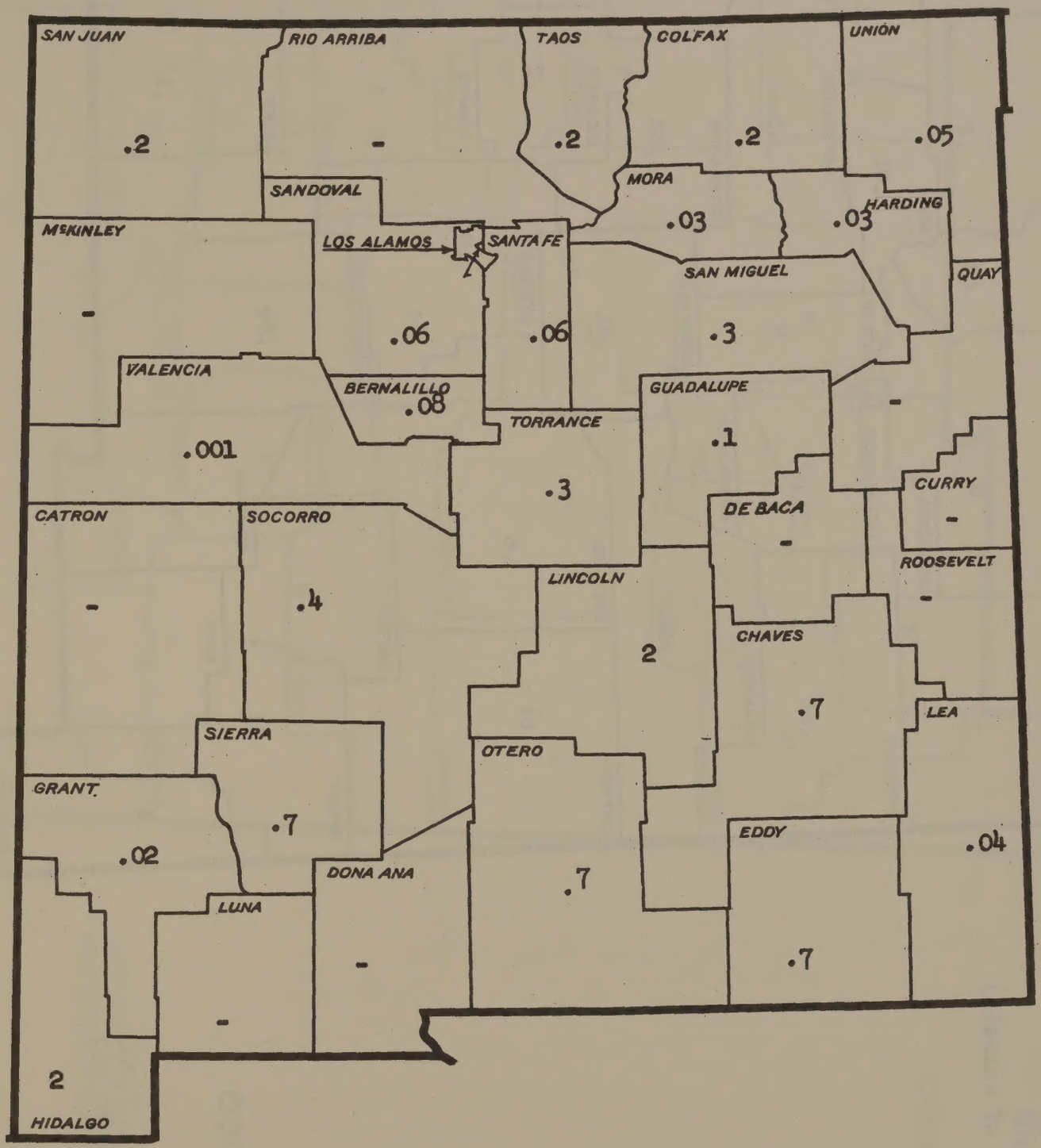
Total 502,500

Value $16,642,000

NEW MEXICO

FIGURE 36

GOAT POPULATION
(In Thousands of Animals)

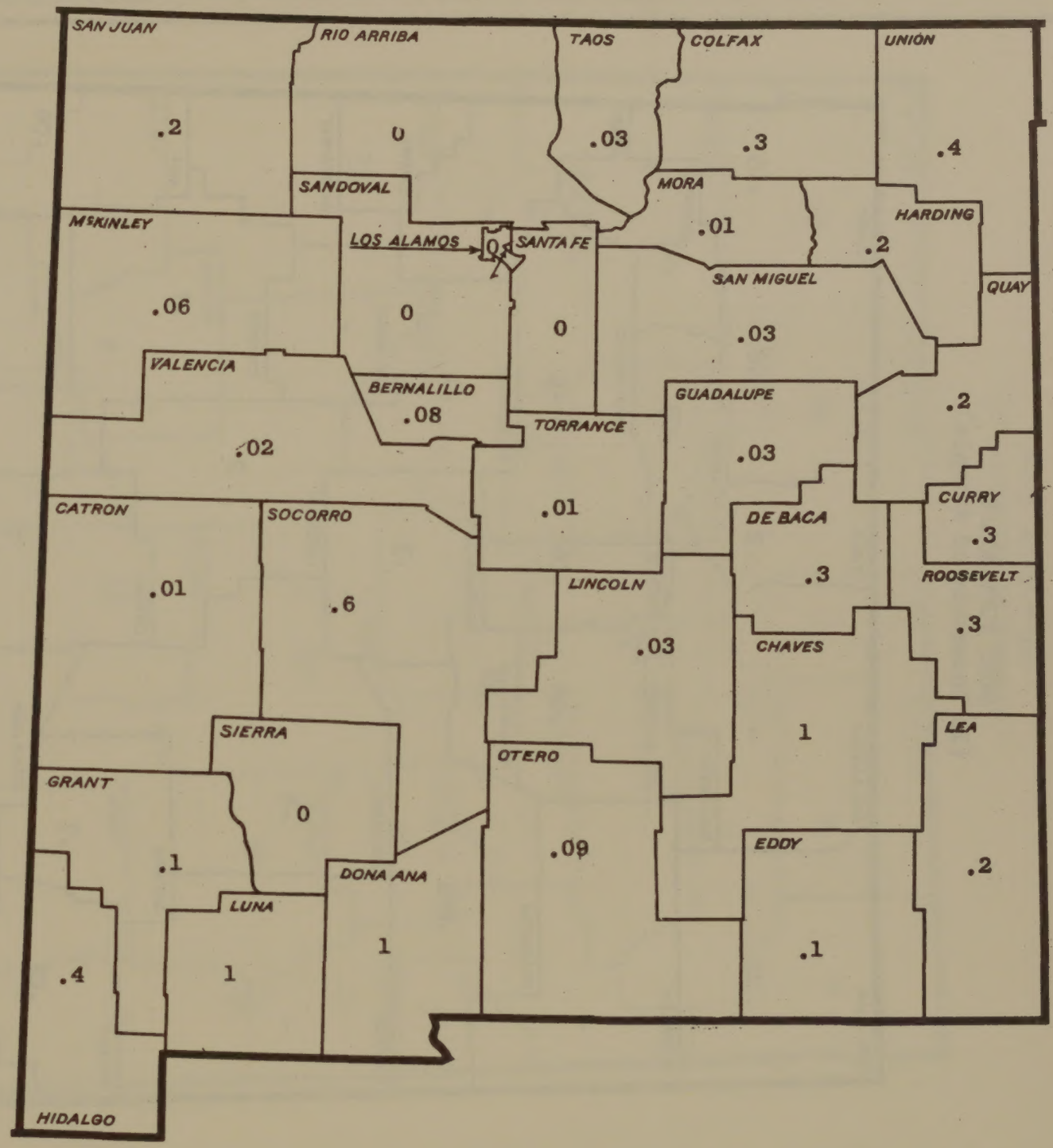


Total - 8,871
Value - $108,000

NEW MEXICO

FIGURE 37

SWINE POPULATION
(In Thousands of Animals)

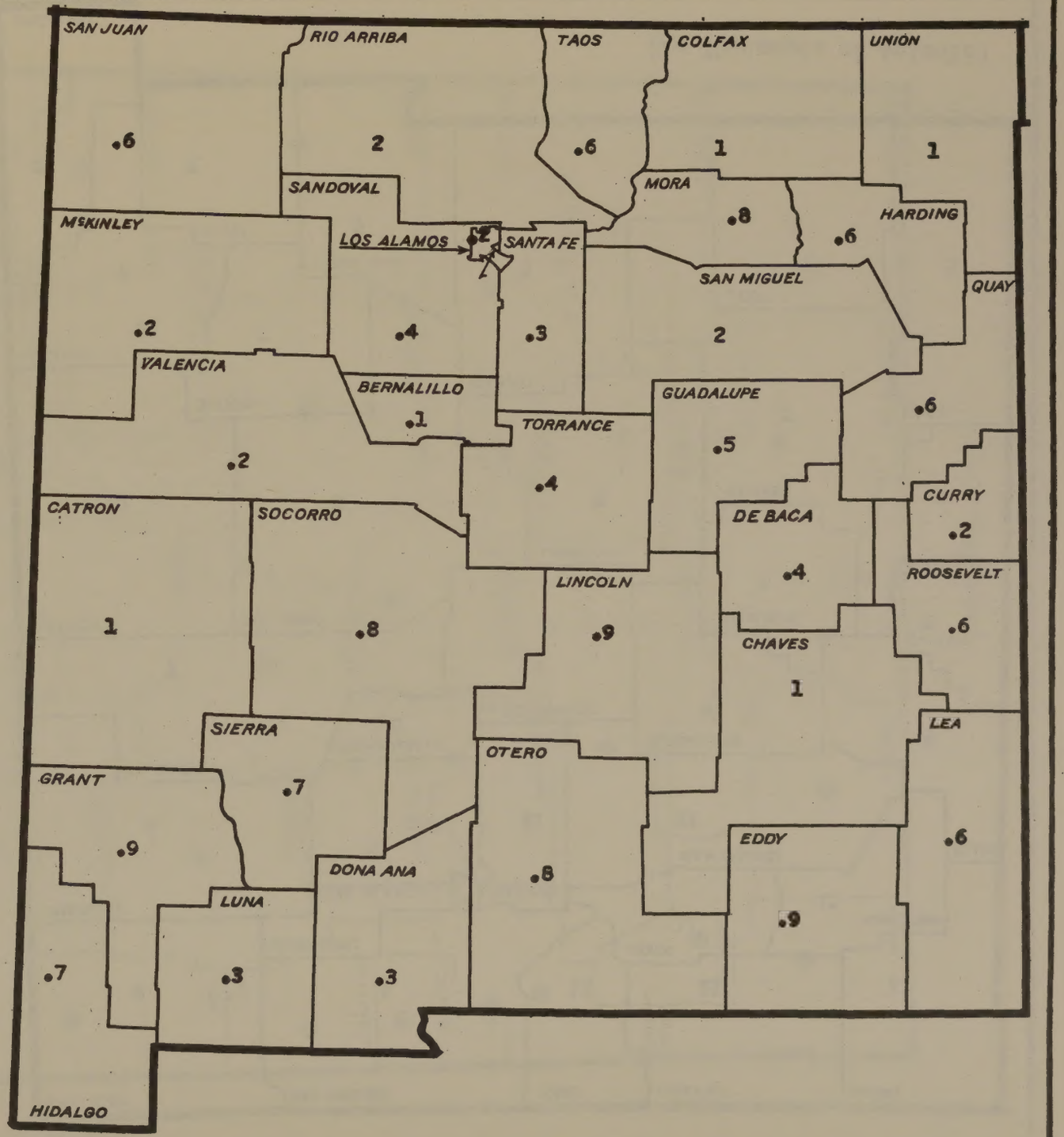


NEW MEXICO

Total	7,000
Value	$780,000

FIGURE 38

HORSE AND MULE POPULATION
(In Thousands of Animals)

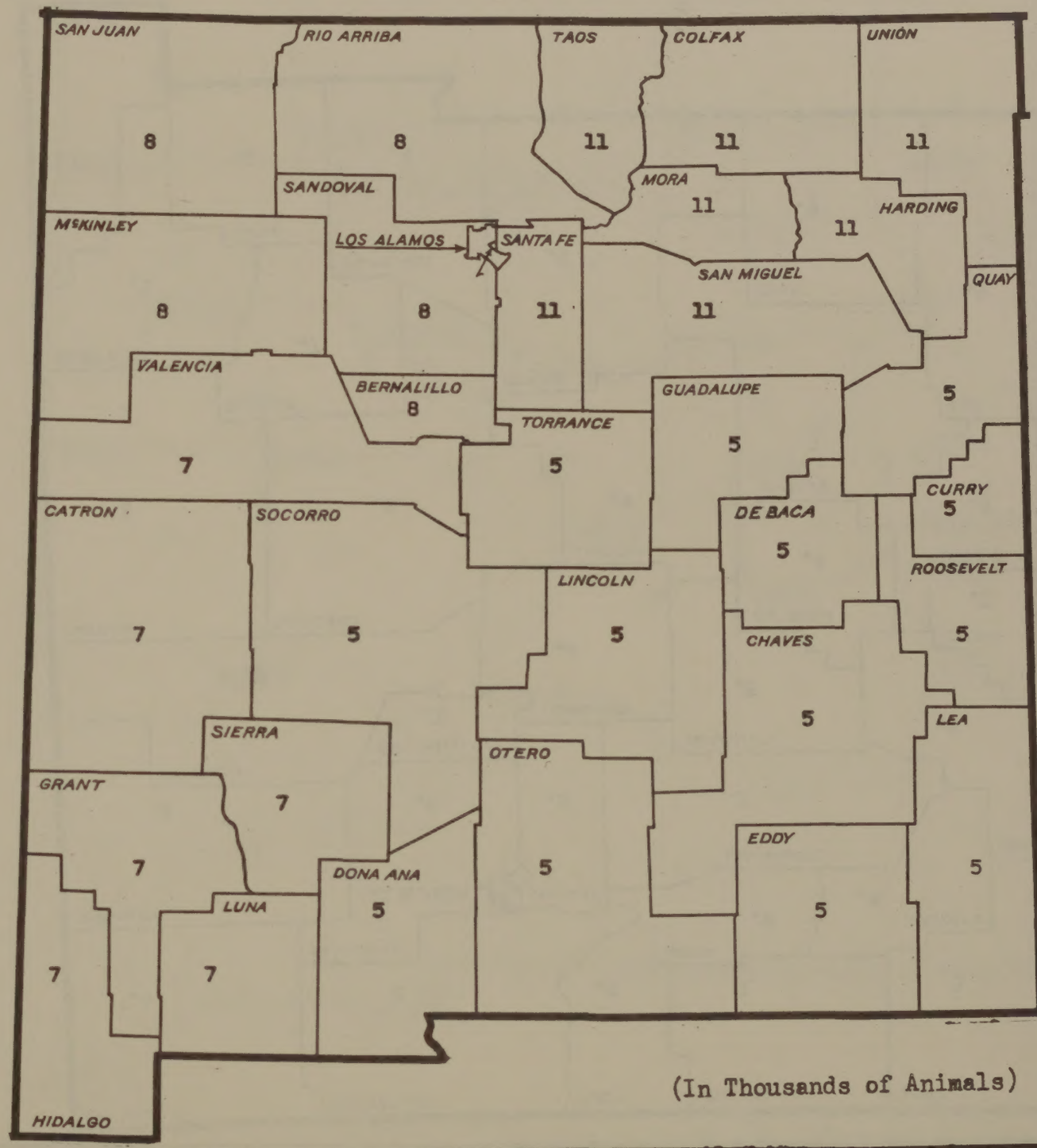


NEW MEXICO

Total	22,000
Value	$3,472,000

FIGURE 39

FIGURE 40

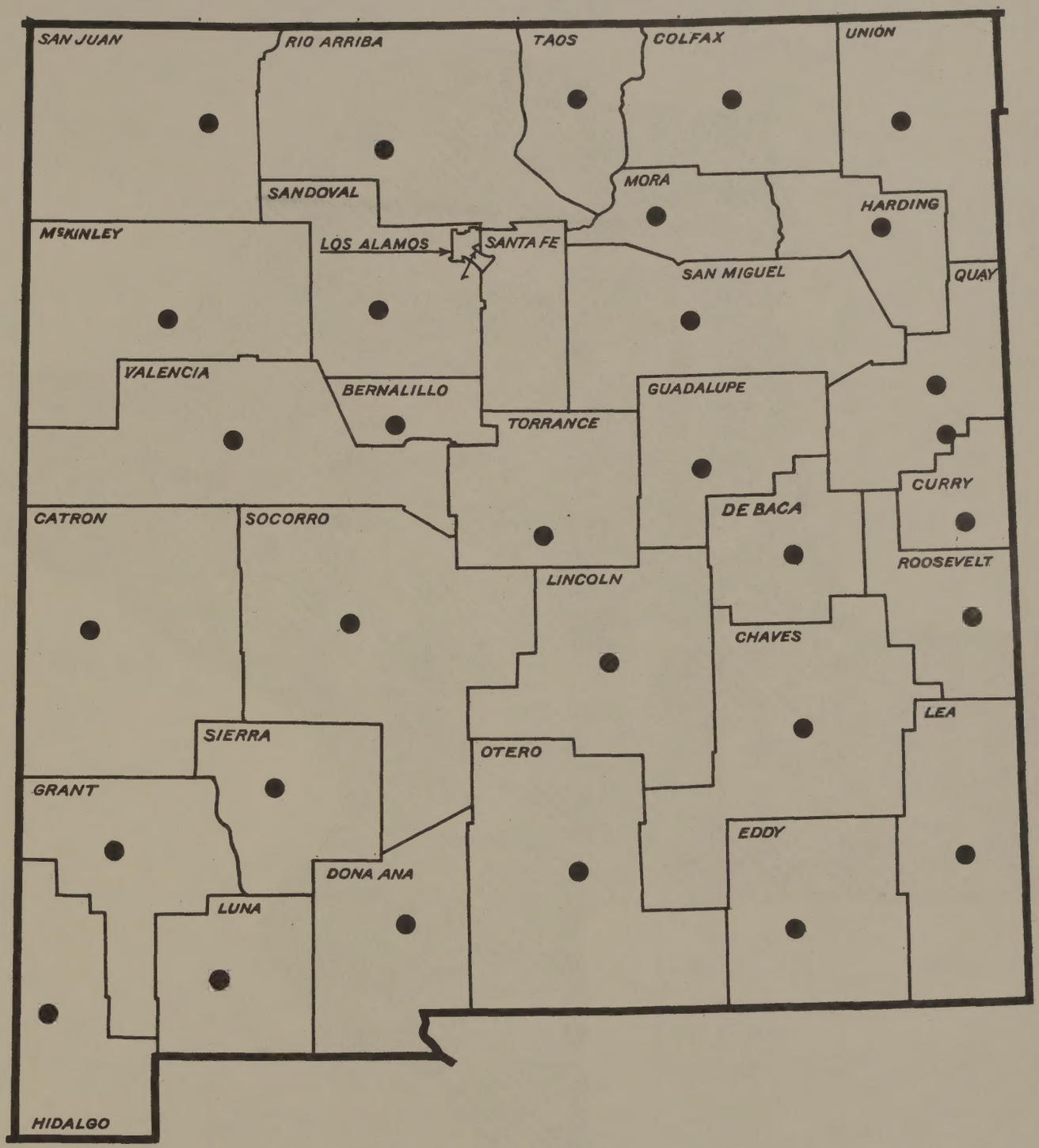


NEW MEXICO

WILDLIFE POPULATION
Total 224,000

(In Thousands of Animals)

SCREWWORM HOSTS



Wild and Domestic Animals

● = 20 per square mile

NEW MEXICO

FIGURE 41

AVERAGE SCREWWORM INFESTATION BY COUNTIES

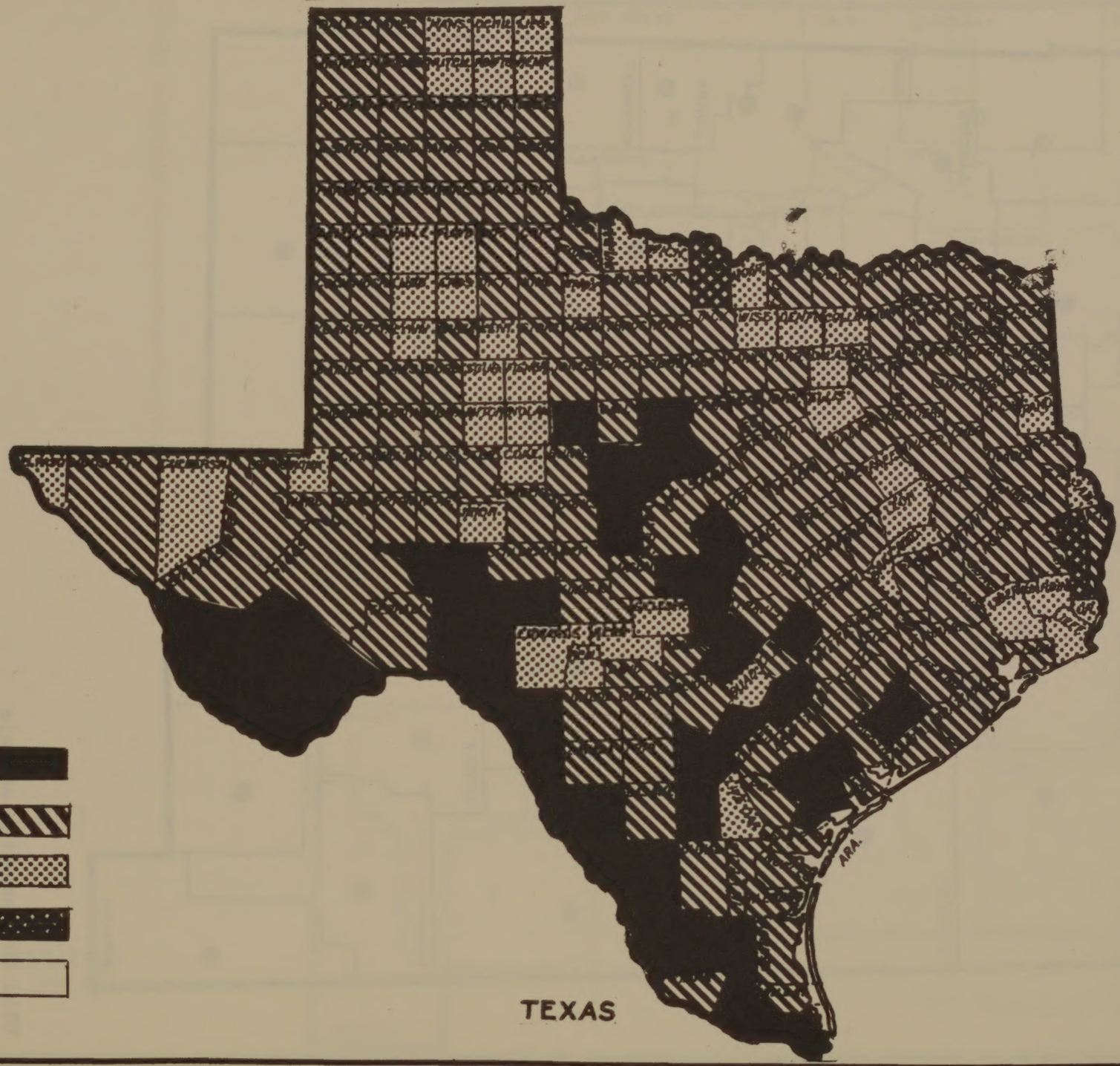
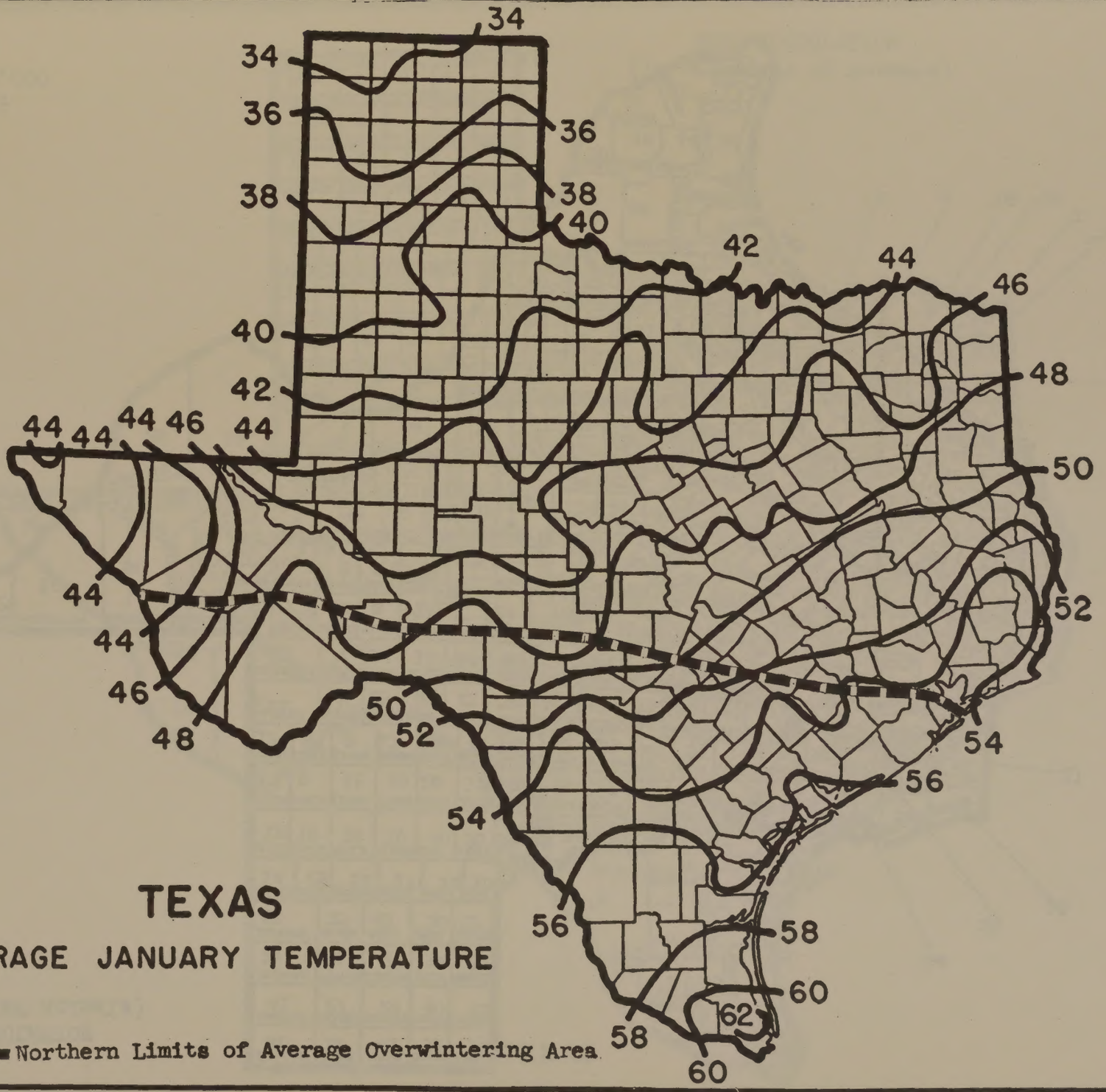


FIGURE 42


34
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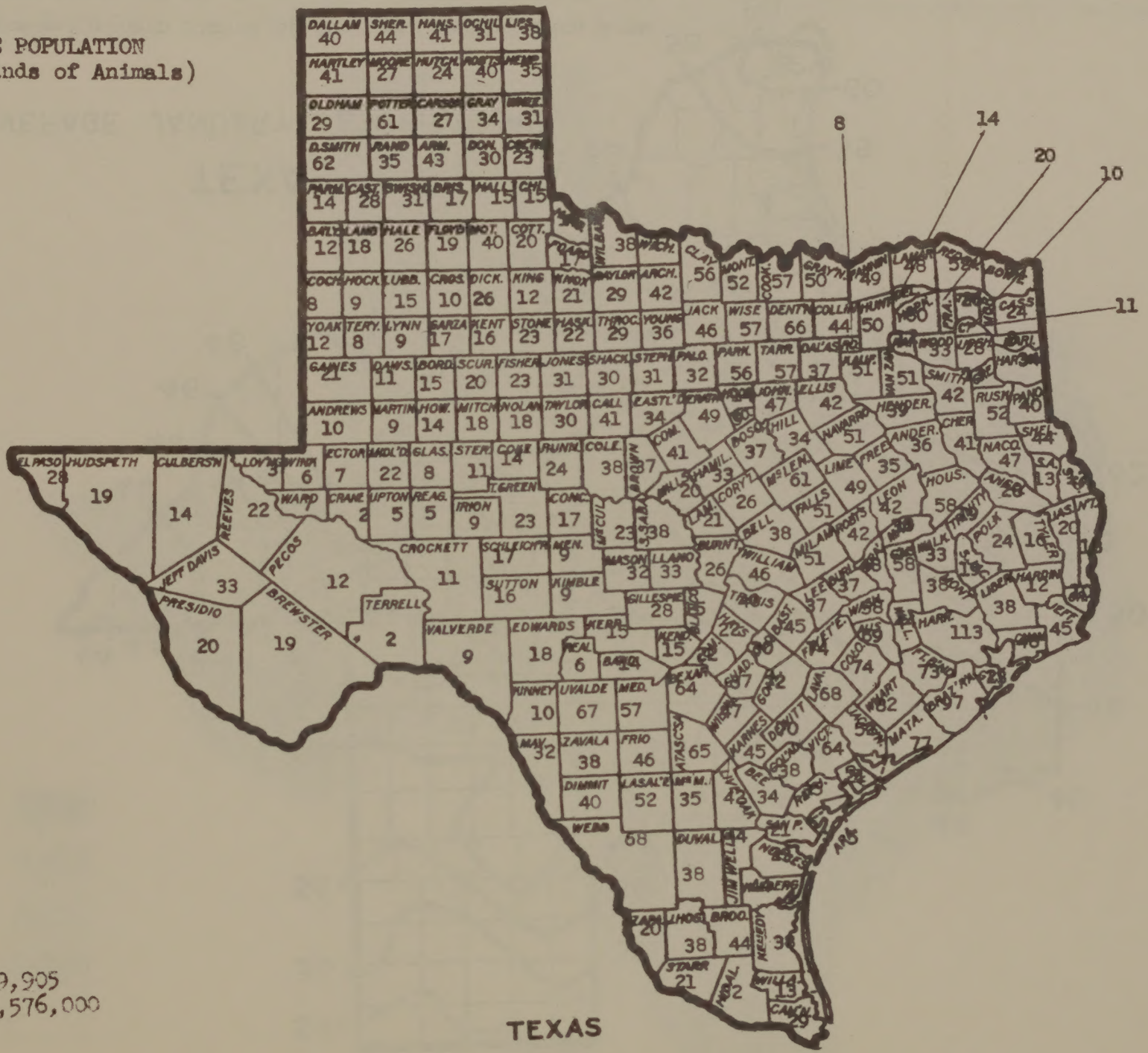
TEXAS
AVERAGE JANUARY TEMPERATURE
Northern Limits of Average Overwintering Area

FIGURE 43

CATTLE POPULATION
(In Thousands of Animals)



Total 8,239,905
Value $510,576,000

TEXAS

FIGURE 44

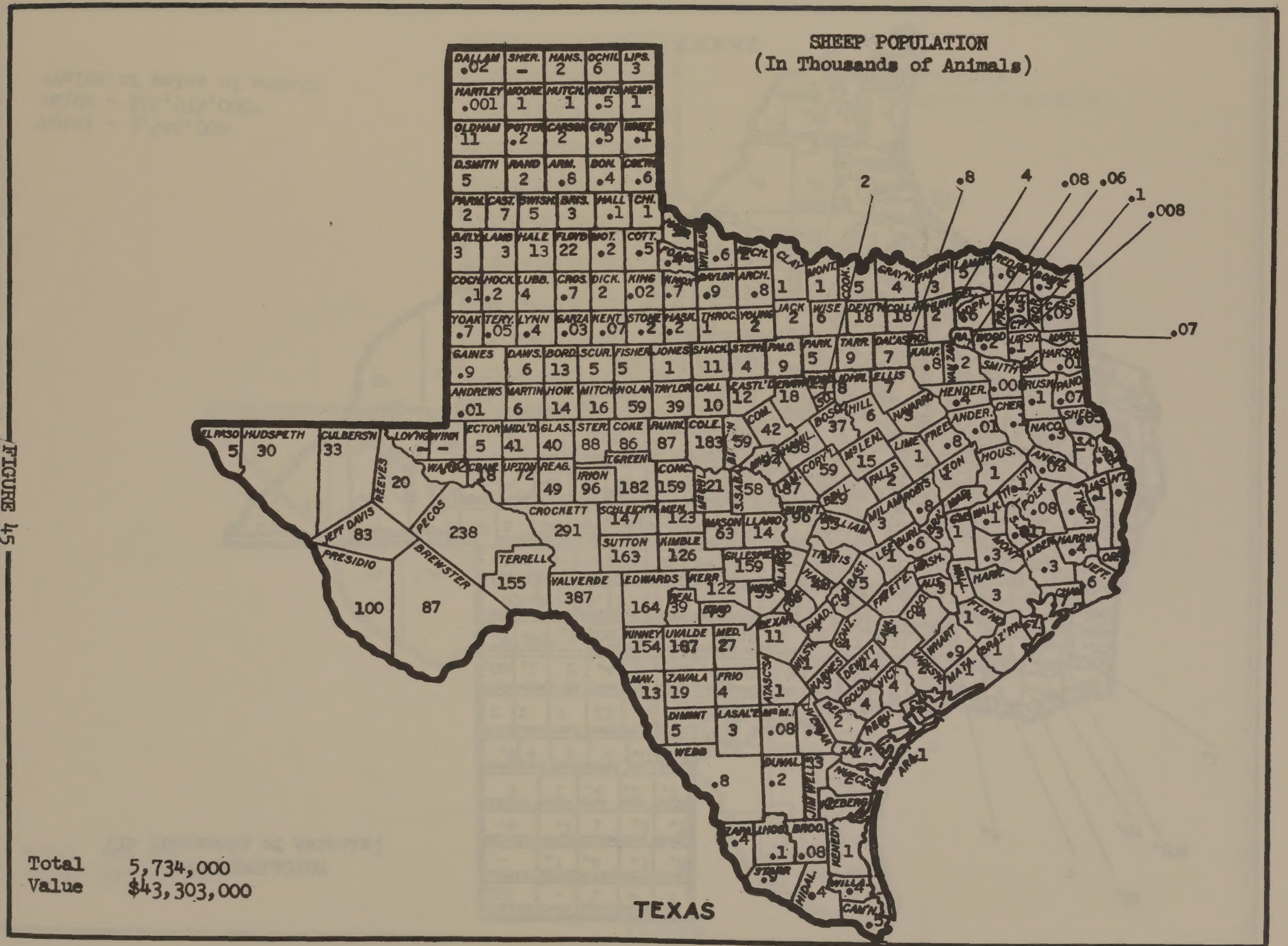
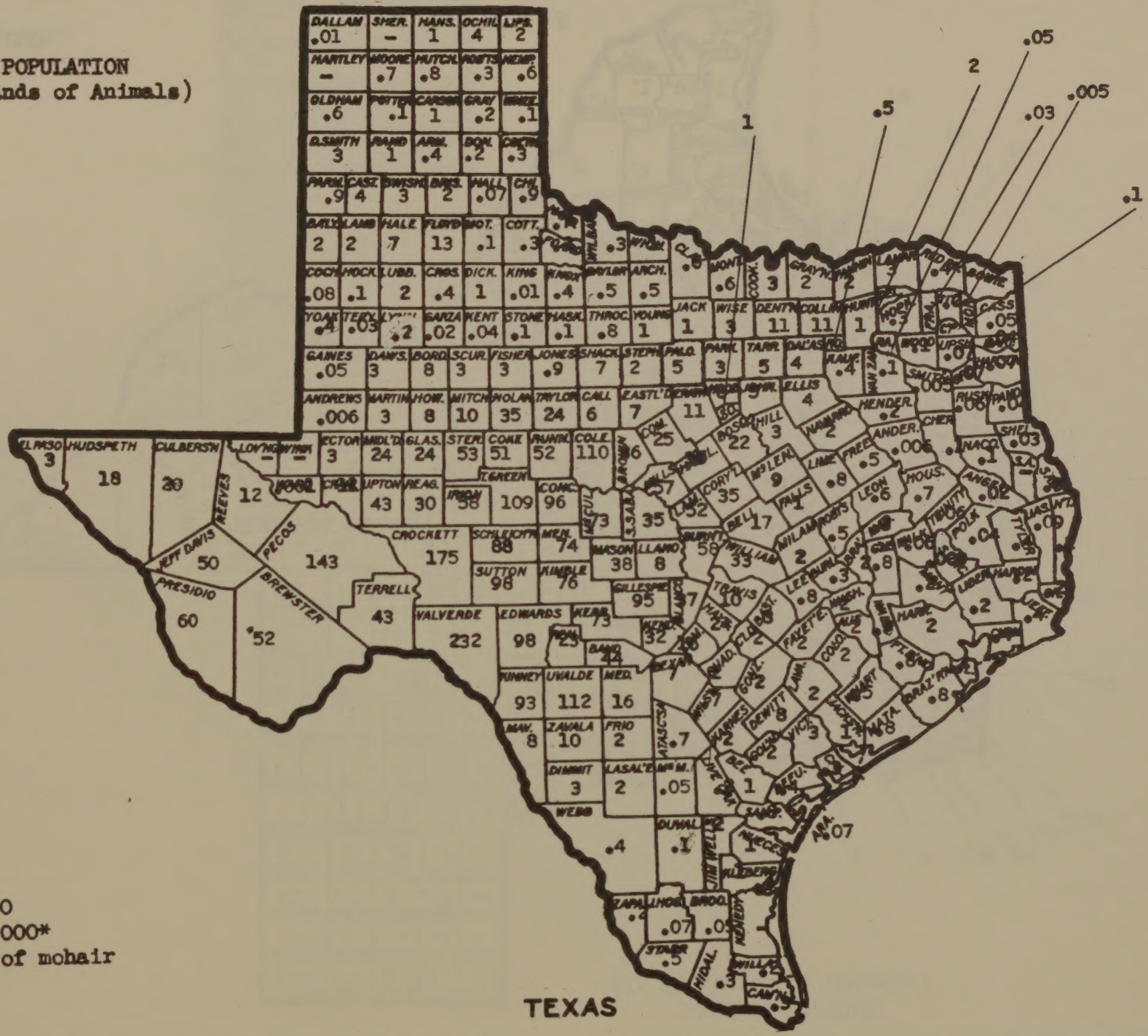

SHEEP POPULATION
(In Thousands of Animals)
TEXAS
Total 5,734,000
Value $43,303,000

FIGURE 45

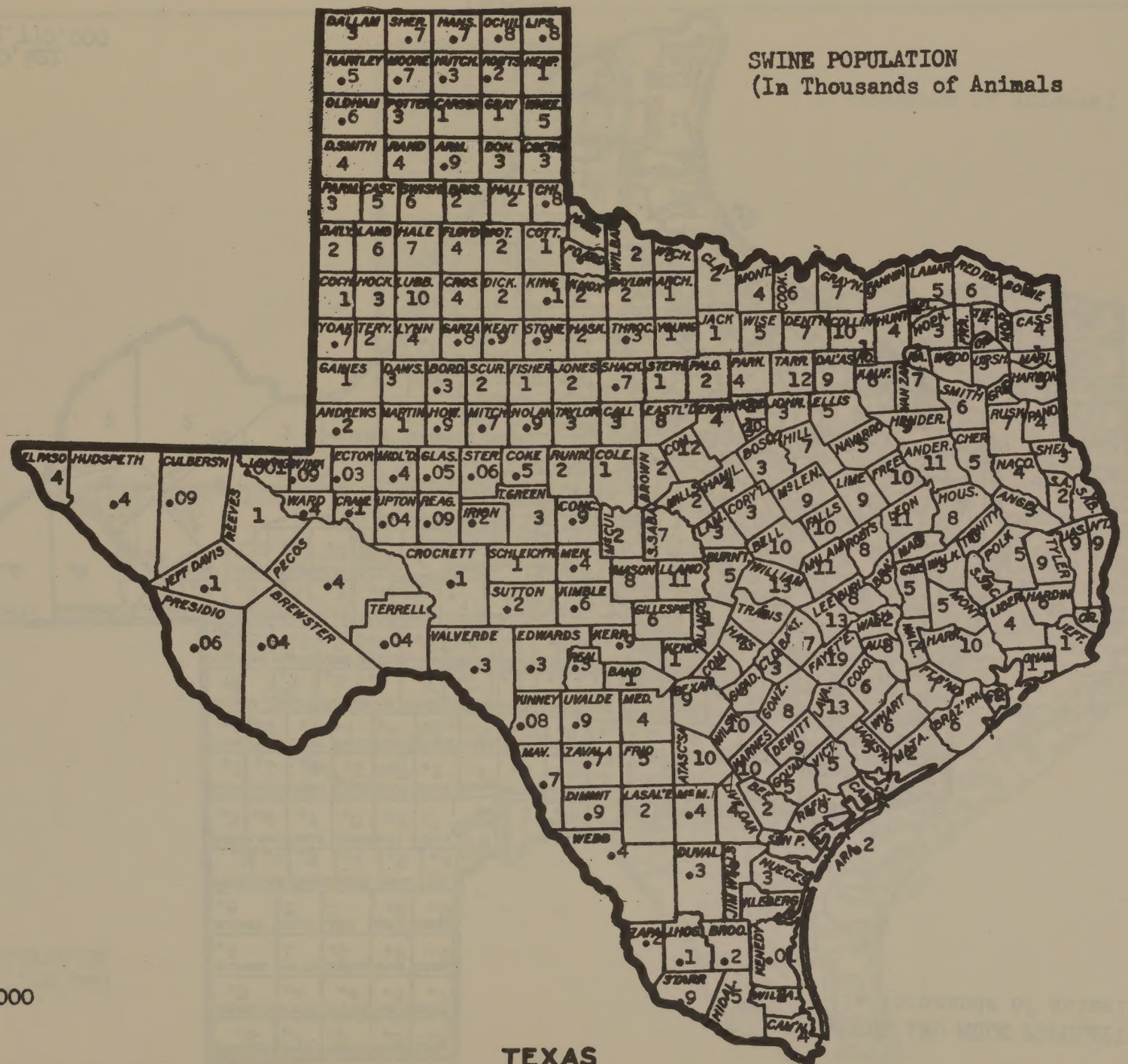
GOAT POPULATION
(In Thousands of Animals)



Total - 3,440,000
Value - $14,974,000*
*Value of sales of mohair

FIGURE 46

FIGURE 47


SWINE POPULATION
(In Thousands of Animals
Total 906,324
Value $15,609,000
TEXAS

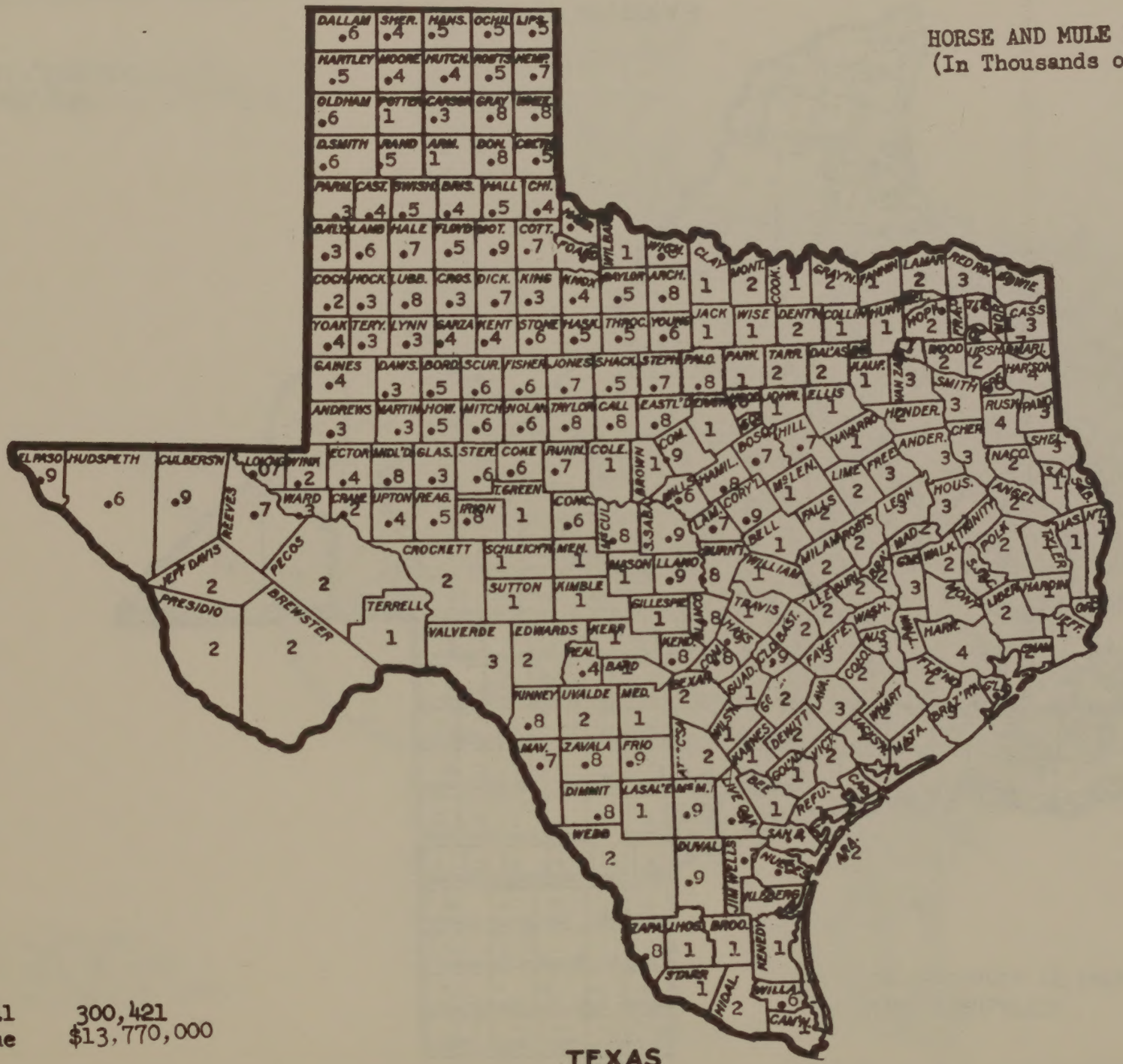

HORSE AND MULE POPULATION
(In Thousands of Animals)
Total 300,421
Value $13,770,000
TEXAS

FIGURE 48

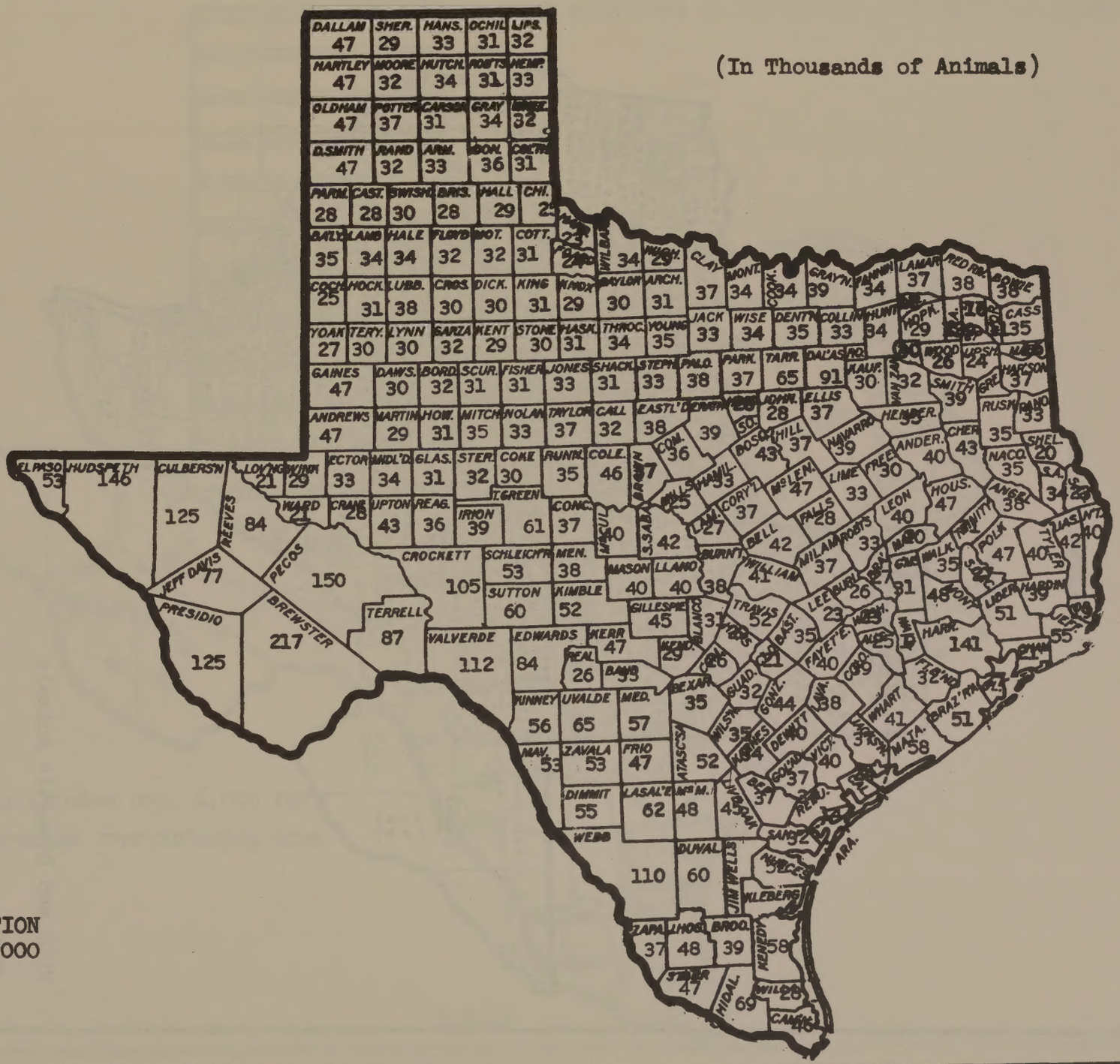
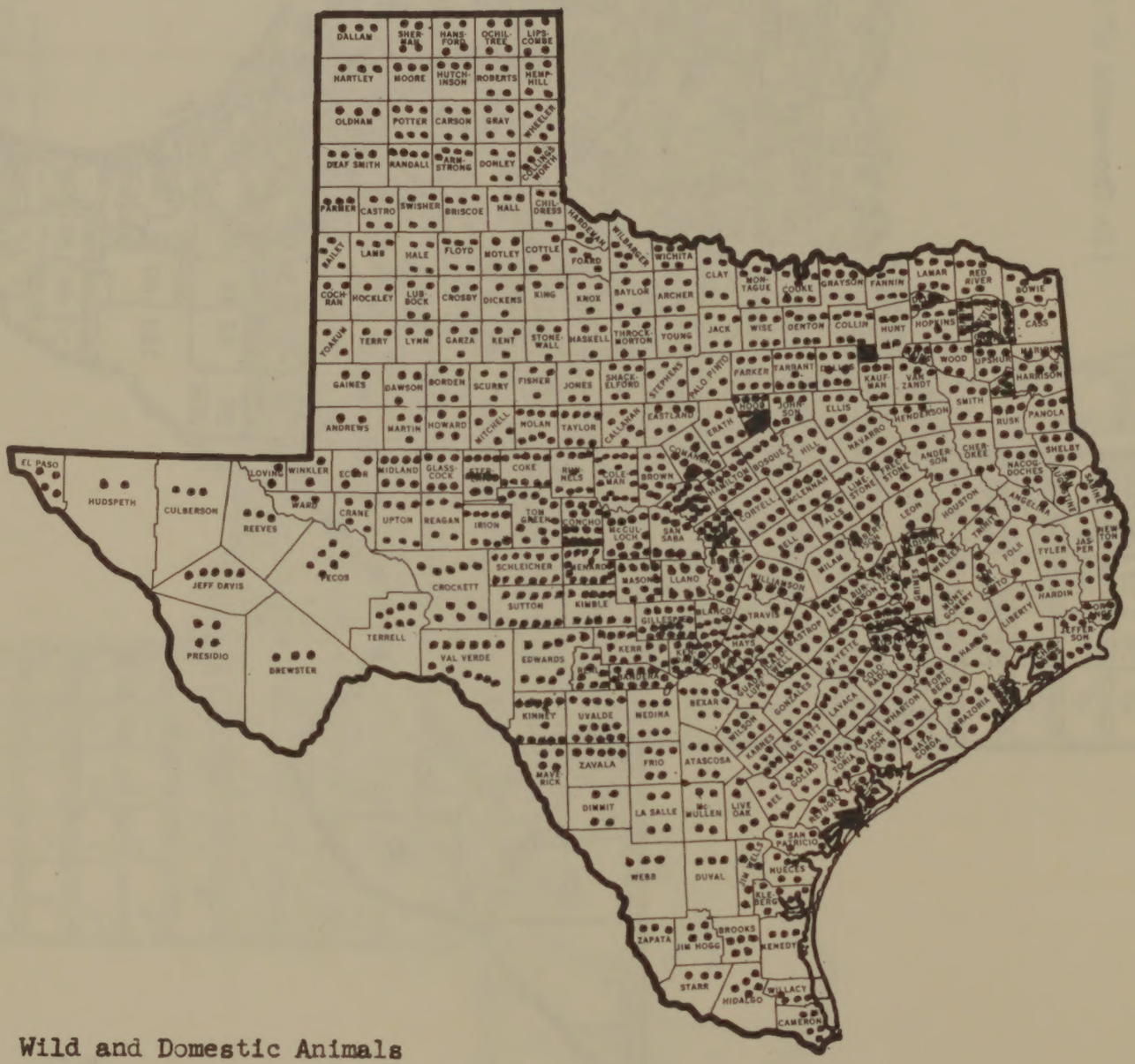

(In Thousands of Animals)
TEXAS
WILDLIFE POPULATION
Total 10,148,000

FIGURE 49

SCREWWORM HOSTS



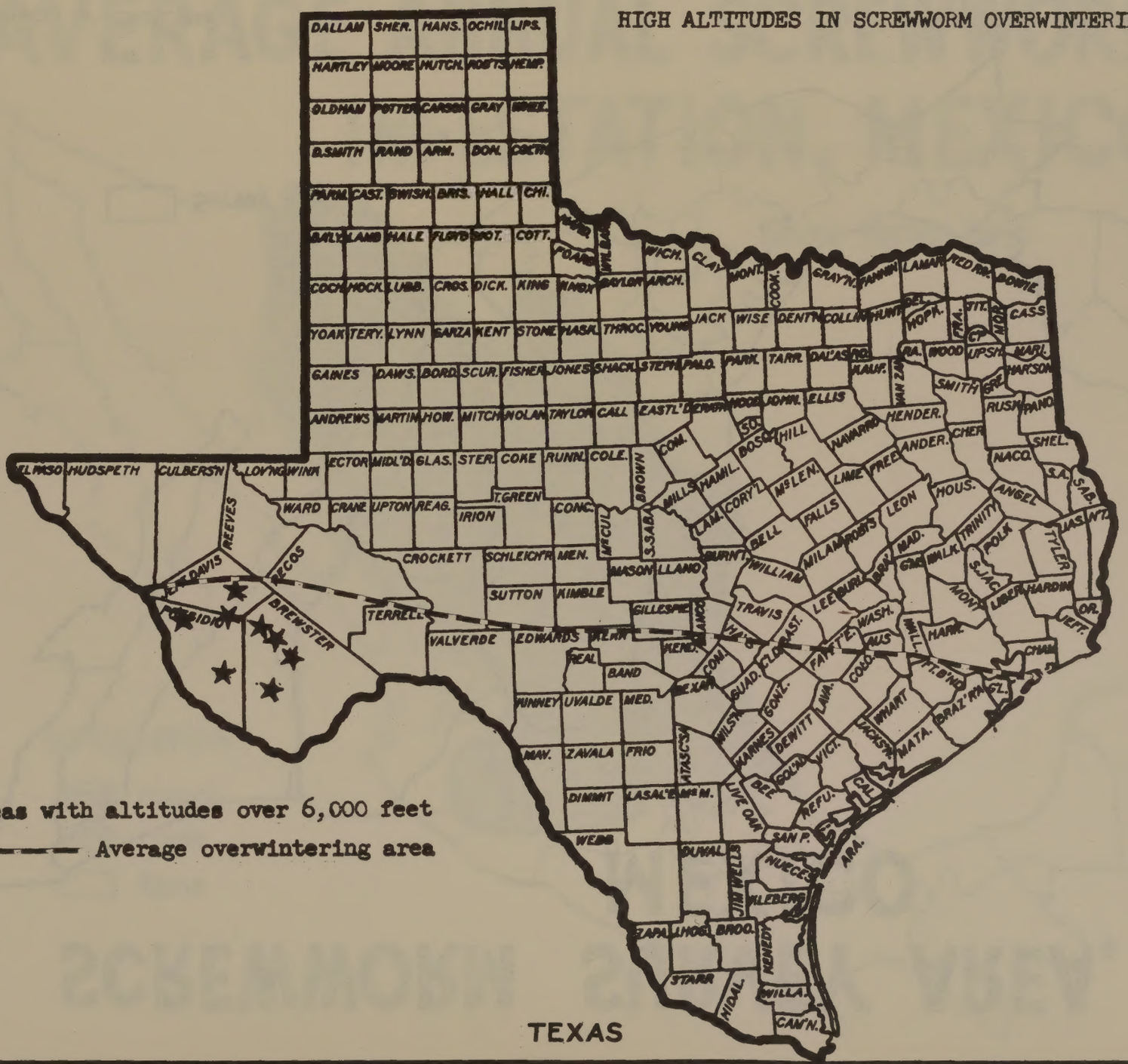
Wild and Domestic Animals

⊡ = 20 per square mile

TEXAS

FIGURE 50

FIGURE 51


HIGH ALTITUDES IN SCREWWORM OVERWINTERING AREAS
Areas with altitudes over 6,000 feet
Average overwintering area
TEXAS

SCREWWORM SURVEY AREA, MEXICO

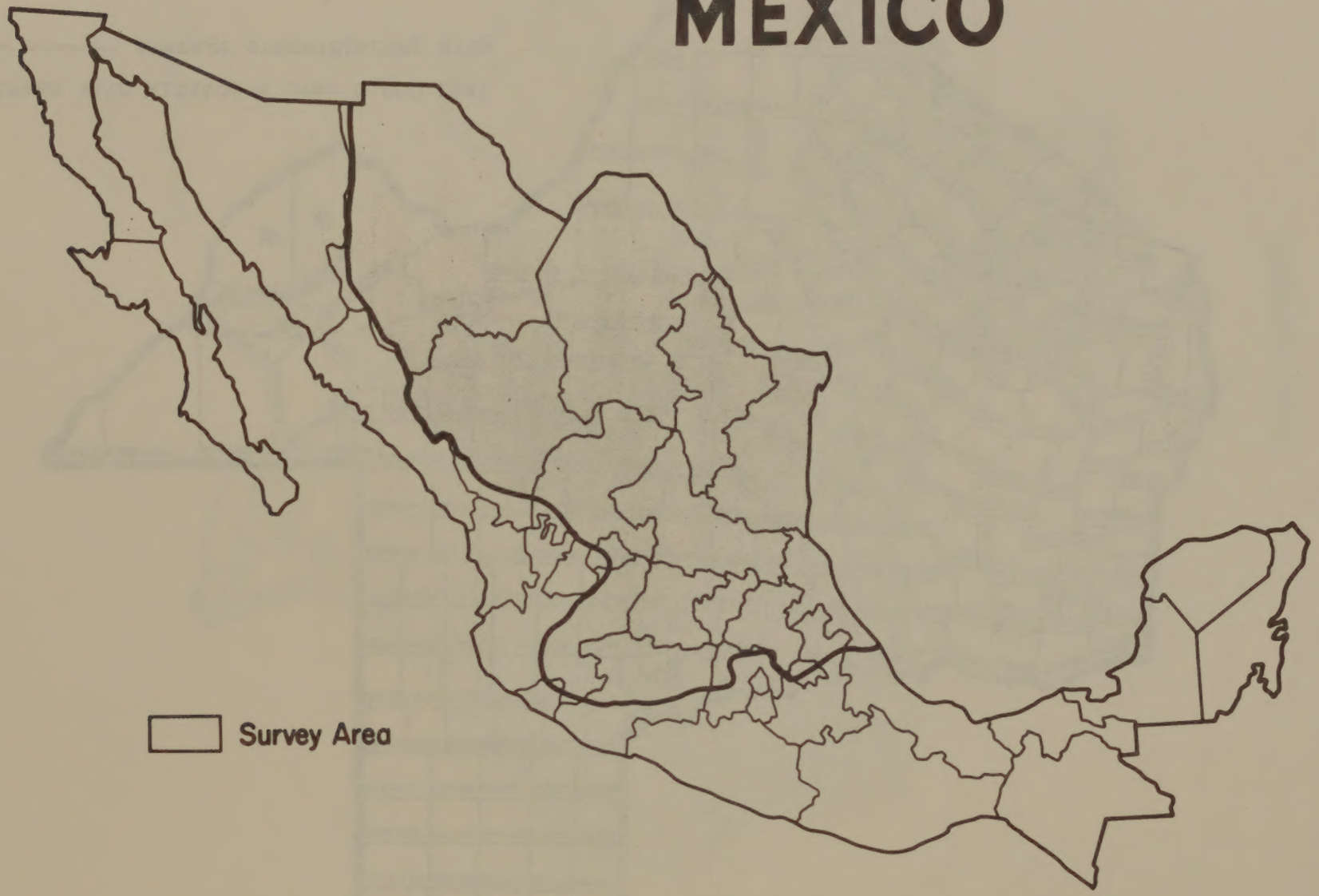


FIGURE 52

U.S. DEPARTMENT OF AGRICULTURE

AGRICULTURAL RESEARCH SERVICE

AVERAGE ANNUAL SCREWWORM INFESTATION, MEXICO

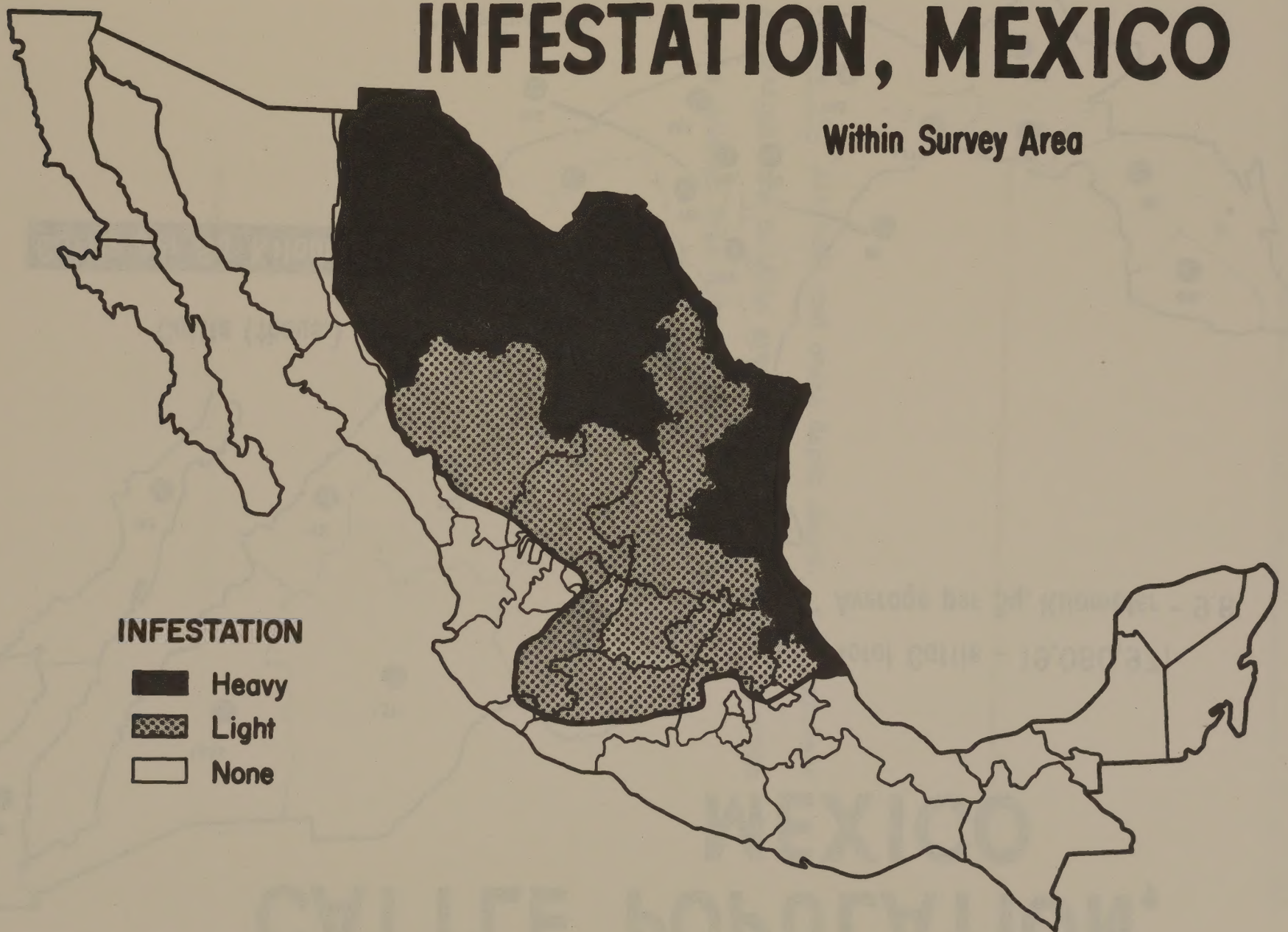


FIGURE 53

U.S. DEPARTMENT OF AGRICULTURE

AGRICULTURE RESEARCH SERVICE

CATTLE POPULATION, MEXICO

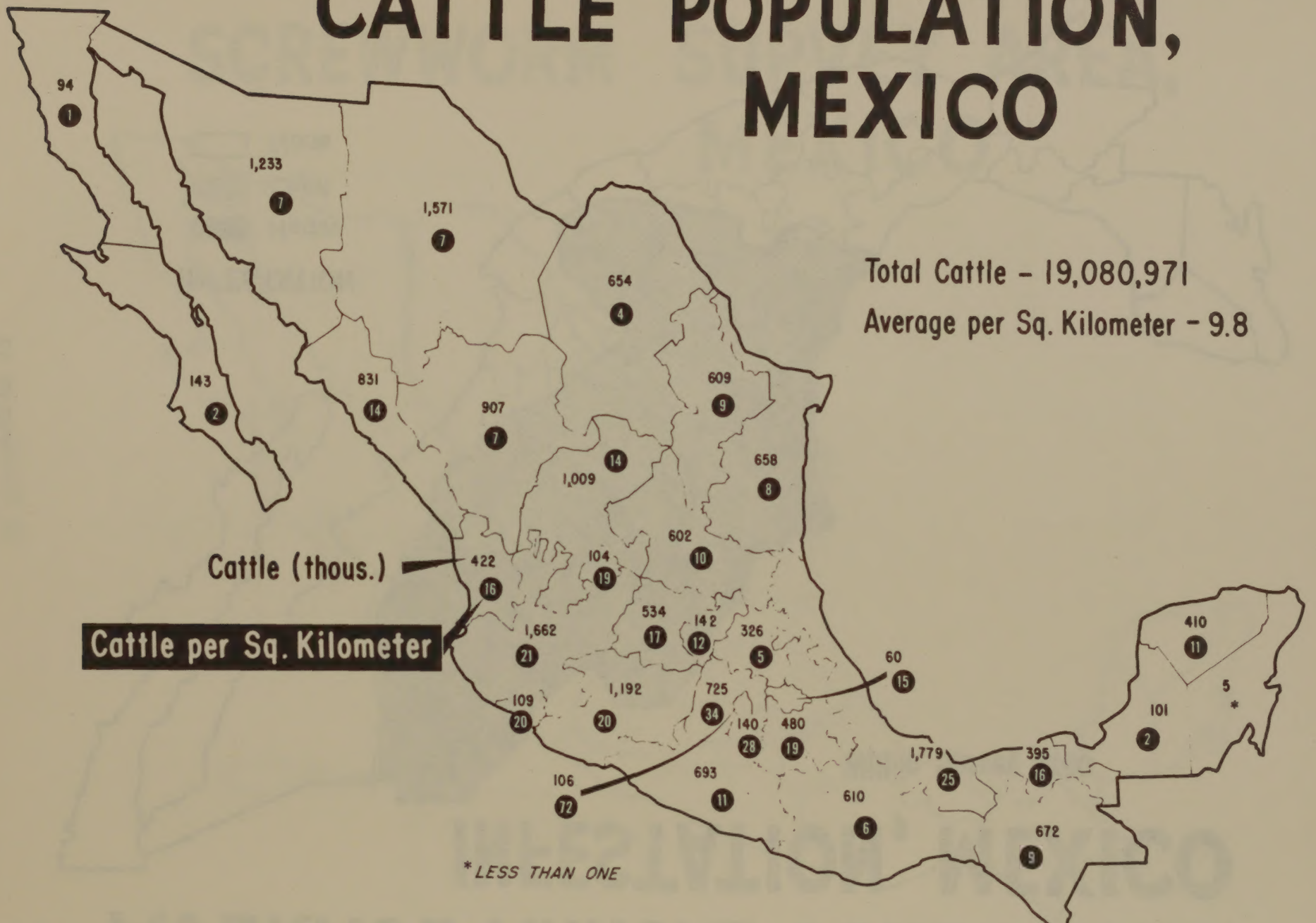


FIGURE 54

U.S. DEPARTMENT OF AGRICULTURE

AGRICULTURAL RESEARCH SERVICE

Figure 55. Altitude and ocean depth chart. Key registers gradations from heights greater than 4,000 meters to ocean depths greater than 6,000 meters.

CARTA ALTIMETRICA

RECOPILACION, CONSTRUCCION Y DIBUJO POR LA SRITA. RITA LOPEZ DE LLERGO,
DEL INSTITUTO PANAMERICANO DE GEOGRAFIA E HISTORIA.

FIGURE 55

MAPA CLIMATOLOGICO DE LA REPUBLICA MEXICANA

Foto-Zincografía de la Dirección de Geog. Met. e Hidr.
Edición 1942

FIGURE 96

Figure 56. Climatological map of Mexico. Key to the map is based on the Thornthwaite system, registering humidity gradations between very humid and very dry, and temperatures from partially cold to hot. Letters used are identified as follows: R--without a well-defined dry season; I--with dry winter; P--with dry spring; V--with dry summer; O--with dry fall; D--with deficient rainfall during all seasons.

SCREWWORM PROGRAM, PLAN NO.1

SW United States and Mexico

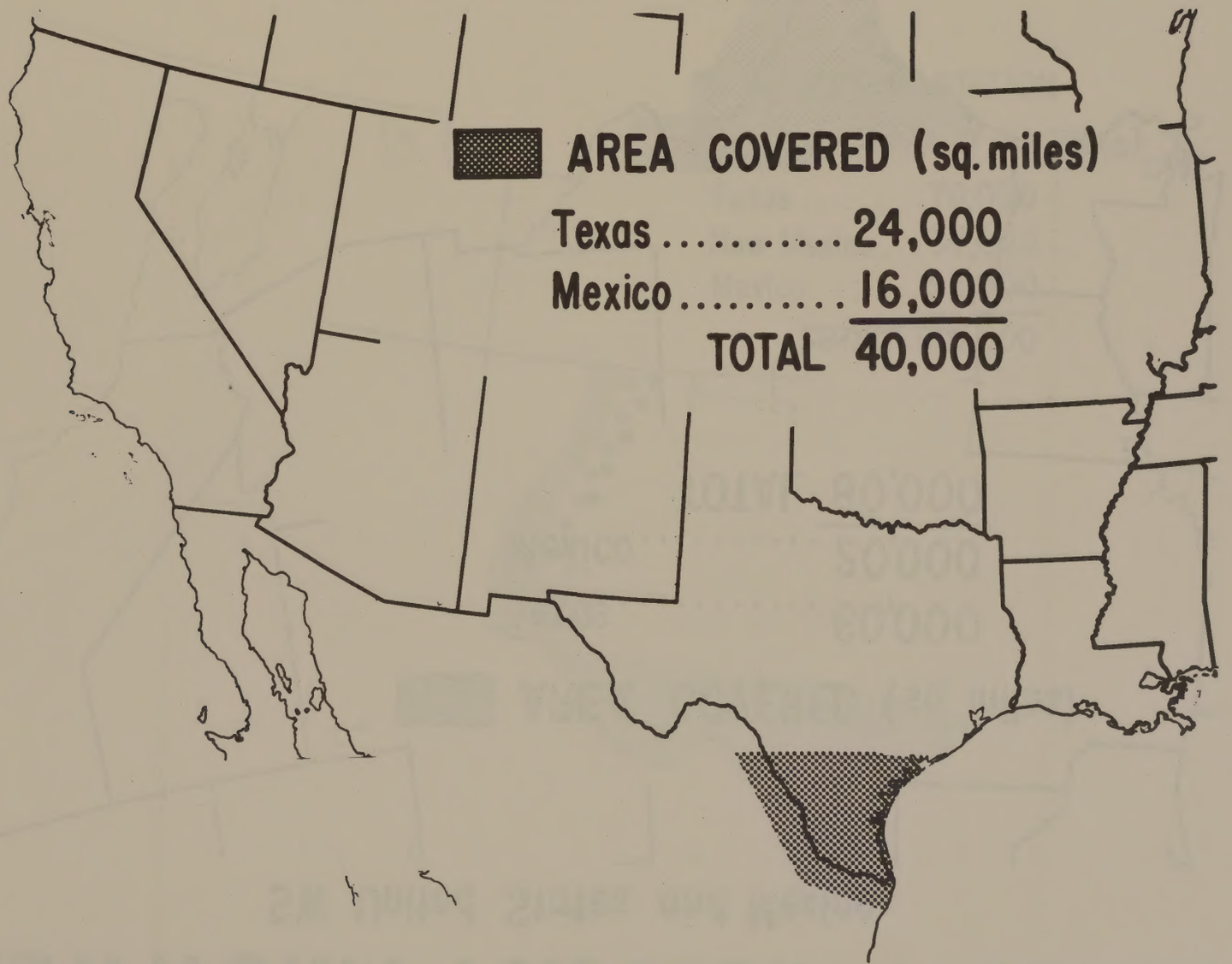


FIGURE 57

U.S. DEPARTMENT OF AGRICULTURE

AGRICULTURAL RESEARCH SERVICE

SCREWWORM PROGRAM PLAN NO. 2

SW United States and Mexico

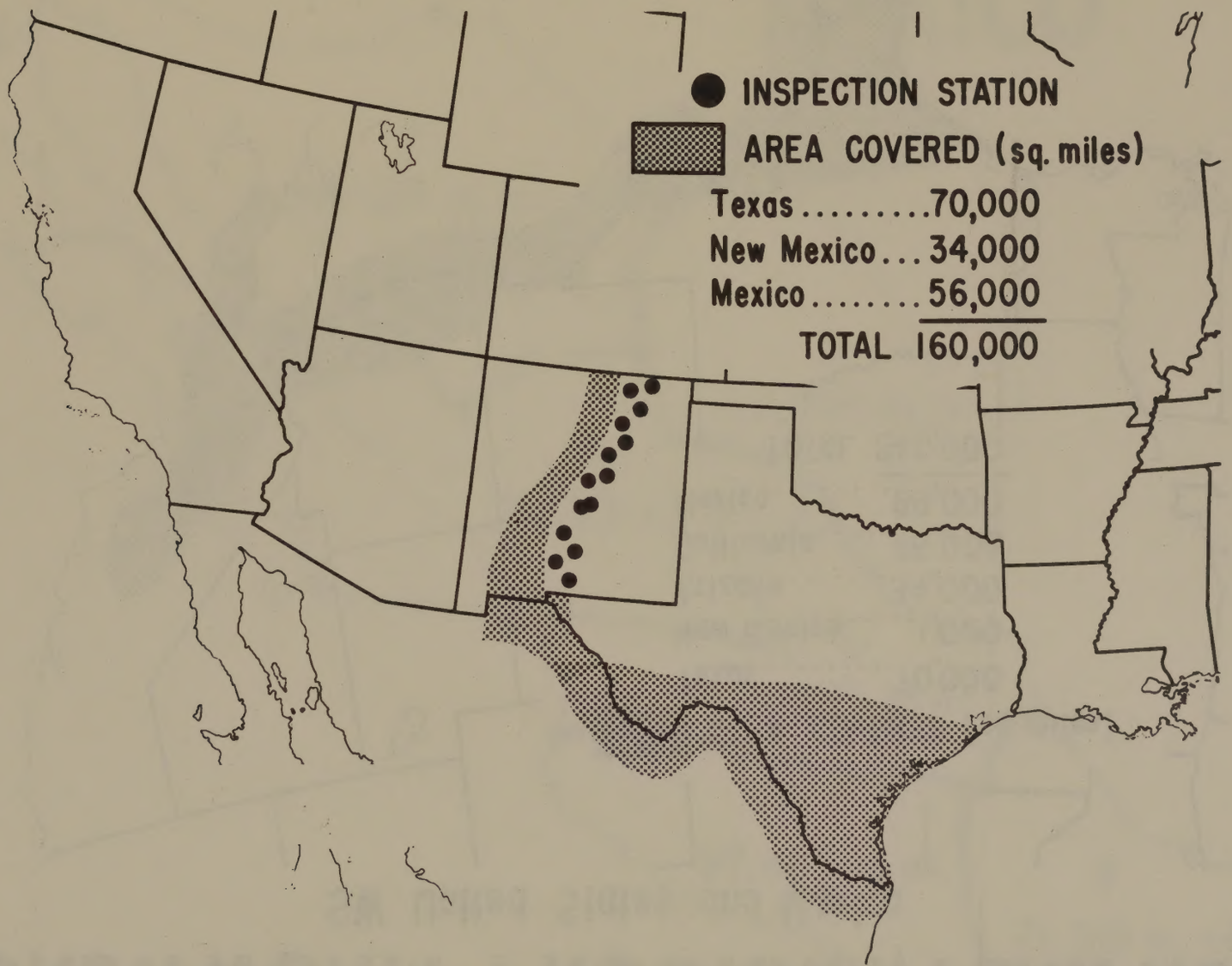
FIGURE 58

U.S. DEPARTMENT OF AGRICULTURE

AGRICULTURAL RESEARCH SERVICE

SCREWWORM PROGRAM, PLAN NO. 3

SW United States and Mexico



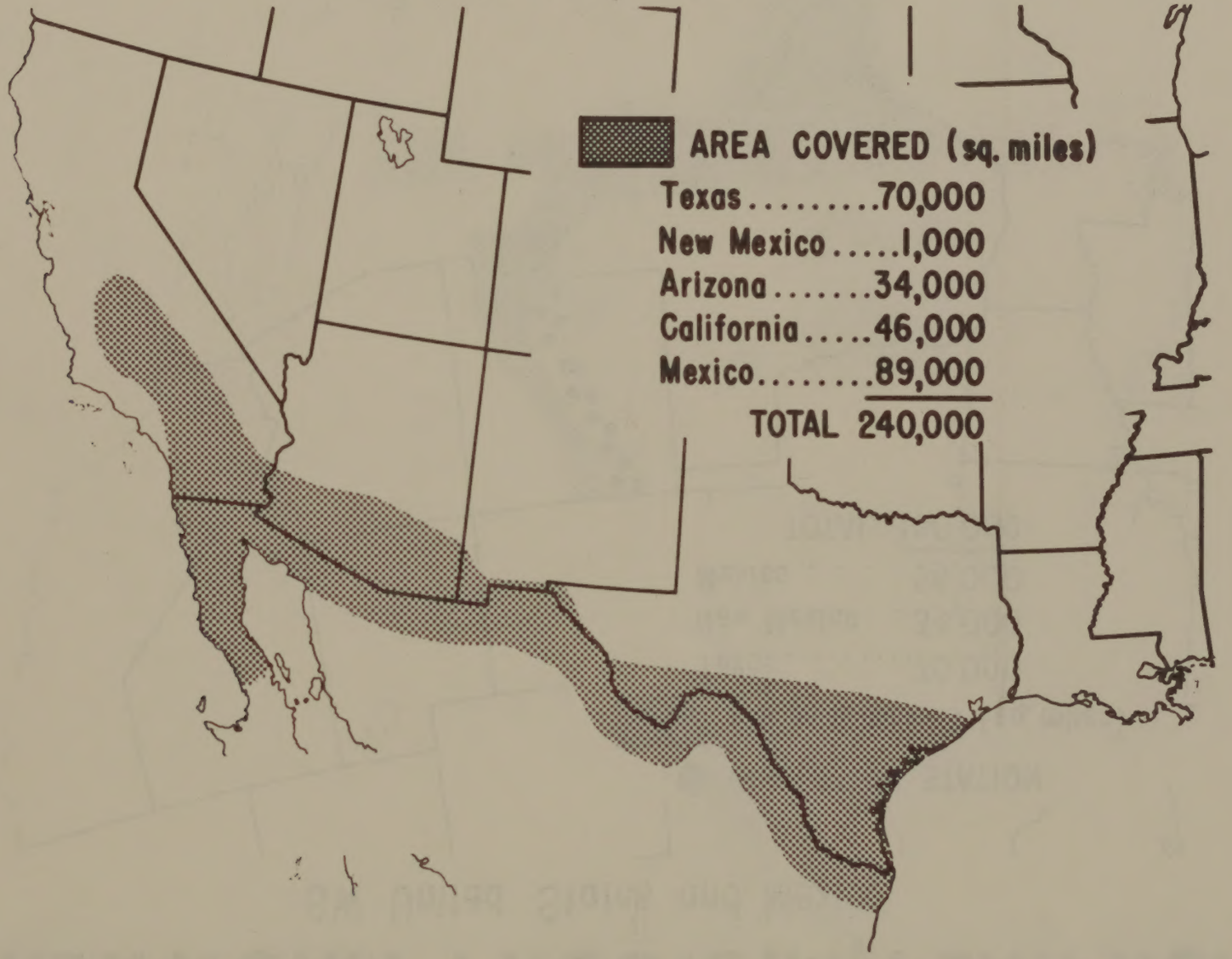
U.S. DEPARTMENT OF AGRICULTURE

ARICULTURAL RESEARCH SERVICE

FIGURE 59

SCREWWORM PROGRAM, PLAN NO.4

SW United States and Mexico



U.S. DEPARTMENT OF AGRICULTURE

AGRICULTURAL RESEARCH SERVICE

FIGURE 60

SCREWWORM PROGRAM AREA, MEXICO

FIGURE 61

U.S. DEPARTMENT OF AGRICULTURE

AGRICULTURAL RESEARCH SERVICE